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RESEARCH ARTICLE

USING OF HYDRAULIC JUMP CHARACTERISTICS AS CRITERION FOR ENERGY DISSIPATION IN RECTANGULAR SHAPED GRAVEL GABION WEIR.

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Abstract

Dissipation of energy of the flow by using of weirs can be accomplish in many ways, depending basically on the type of weir. The concept of through and overflow for porous weirs can be use purposively to explain many phenomena such as, dissipating the energy of incoming flow which the flowing of water through the body of the weir contributes in considerable percentage of it, and using of another concepts to represent the dissipated energy in the downstream side of the weir as criterions for energy dissipation. This paper aims to study the dissipated amount of energy for gravel gabion weir by choosing of the difference in energy between upstream and downstream sides of the weir, and the distance of formation of the hydraulic jump as criterions to represent the energy dissipation. The general conclusion shows that both criterions are directly proportional with each other for all series of test runs, while every parameter, fixed of measured, such as length of the weir and diameter of gravel sample has an undular effect on both criterions.

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Introduction:-

A lot of studies and researches have been carried out to study and discuss various topics concerning flow behavior in weirs. In order to coherent these topics, it's important to study and realize hydraulic structures from different aspects such as, study the hydraulic characteristics of flow over solid weirs, flow through and over pervious weirs, energy loss and energy dissipation of flow in weirs. This paper aims to study the dissipated energy of flow for the rectangular shape of "Gravel Gabion Type" weir.

Hydraulic Characteristics of Flow:-

Studying of the characteristics of flow through and over weirs consider as the main and one of priority objects that can be discuss to explain different types of flow phenomena that can occur in various water resources projects. Studying of hydraulic characteristics of flow helps firstly, to find a proper analogy to create a comparison between solid and rockfill weirs in over flow case. Secondly, make a possibility of use empirical equations to understand the behavior of flow through and over rockfill structures [6], [15], and [16]. Examples of hydraulic behavior in weirs are much more than correspond herein, and differ according to the aim of study. Such examples as describing various relationships for non-Darcy flow in rockfill material, by considering the friction factor- Reynolds number, and hydraulic gradient-bulk seepage velocity theoretical relationships as main relations. In addition, making a comparison with various formulas for rockfill available from literature by computer simulation [3]. Reanalyzing the

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characteristics of the free surface undulations downstream the first wave crest for undular flows and undular hydraulic jumps, by depending the relationship between wave amplitude and the approach flow Froude number [5]. Investigation of flow over gabion weirs by Performing a series of laboratory experiments, and using the relationship between the parameters such as, discharge, upstream and downstream water depths, weir height, weir length, and gabion filling material [7]. Determination of flow conditions through and over rockfill embankment, by taking the free surface flow regime as spatially varied, and the seepage flow regimes as non-Darcian for two conditions of flow. The partial overtopping and complete overtopping [8]. Finally, studying the hydrodynamics of a rubble mound weir in both theoretical and experimental sides. Performing a one-dimensional analysis on a steady non-uniform flow through the weir. Where the discharge as a function of related parameters, such as flow depths on upstream and downstream faces of the weir, porosity, weir length, and grain diameter of the rubble mound [12].

Energy Loss of Flow in Porous Weirs:-

A complete understanding of the energy losses in porous weirs is necessary to find the proper relationship for this topic. Reference [4] studied the energy loss at drops by investigating the dissipated energy of three drops with different heights as physical models made of Plexiglas, and installed in two laboratory flumes. By using an artificial neural networks approach. He developed an explicit procedure to calculate the resulted energy loss by NeuroSolutions. His results showed that the energy dissipation in drops depend on the drop height and discharge. The predicted relative energy dissipation varied from 10% to 93.4%. Finally, the energy loss at drops is mainly due to mixing of the jet with the pool behind the jet that causes air bubbles entrainment in the flow. Reference [9] studied the energy loss through porous dykes with different shapes and materials experimentally. He used the friction factor – Reynolds number relationship as a representation for the head loss through the body of the dyke. In addition, the influence of another parameters such as stone shape and porosity on the relationship. He noticed the contrary attitude between parameters in his relationship, and concluded that the friction factor for the same Reynolds numbers for the used shapes were in agreement with one another, and affected by stone angularity and porosity. Reference [18] evaluated an empirical equations to estimate the hydraulic parameters of the non-linear flow through coarse porous media. He used a series of independent data collected in the laboratory, resulted from testing three different relatively uniform soils with three random samples drawn from each material. The equation was performed for the physical characteristics such as size distribution, porosity, and shape factor for all samples. The statistical analysis showed that the performed equation can give good results compared with literature formulas that used in the same field measurements representation, and show acceptable performance. Reference [20] proposed a head loss equation for flow through rockfill to be acceptable for a wide range of rock particle size. In addition, using it for prediction of flow transmissibility of rockfill structures by selecting the Forschheimer equation to describe the head loss property of flow through rockfill. The study was summarized by considering Forschheimer equation as the best formula that can be applied to rockfill particle size from 5 mm to about 100 mm, and to predict flow transmissibility of rockfill structures.

Experimental Work:-

All tests were carried out in the hydraulic laboratory of College of Engineering of the Babylon University in Iraq. The laboratory has a tilting flume of 10 m length, with 0.3 m width and 0.5 m height. The bed of flume was fabricated from iron plates and the flume side walls were made of anti-crush glass supported by stainless steel bars. The physical models that used have lengths of 40, 60, 80, 100, and 120 cm, and named as GGW.No.1, (Gravel Gabion Weir Number 1), GGW.No.2, GGW.No.3, GGW.No.4, and GGW.No5 respectively. All models have constant cross-section, (width of 30 cm and height of 40 cm). While the gravel samples that used as filling material for the weir models were five monosized gravel samples with diameters (9.5-14), (14-19), (19-25), (25-37.5), and (37.5-50) mm, and numbered as G.S.No.1, (gravel sample number1), G.S.No.2, G.S.No.3, G.S.No.4, and G.S.No.5 respectively. The frame of GGW was made of thin steel plated bars, covered by a wire mesh, and fixed inside the flume by silicone glue. A photo of GGW.No.1 with G.S.No.1 illustrated in Fig. 1. A centrifugal pump having a rated capacity of 40 l/s was used to deliver flow to the flume. Two movable carriages with point gages were mounted on brass rail at the top of flume sides which have accuracy of 0.1 mm to measure the depths of water. The first was located at the upstream side of GGW and measures the upstream water depth at equal distances 0.0, 0.2, 0.4, 0.6, 0.8, and 1.0 m before GGW during the single test run. The other was at the downstream side of GGW and measures the downstream water depths before and after the hydraulic jump location during the single test run. A total of 194 test runs were carried out and varied between minimum and maximum values of discharges recorded from 0.70 to 14.025 l/s respectively.

The Concept of Energy for GGW:-

The magnitude of energy at the upstream side of GGW can be calculated by:

$E_u = Z_u + y_u + \frac{v_u^2}{2g} = Z_u + y_u + \frac{q^2}{2gy_u^2}$	(1)
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where E_u is the magnitude of energy at the upstream side of GGW (m), Z_u is the elevation head directly under y_u (m), y_u is the upstream water depth of GGW (m), v_u is the velocity of flow at the upstream side of GGW (m/s), g is the gravitational acceleration (m/s²), and q is the discharge per unit width (m³/s/m). While, the magnitude of energy at the downstream side of GGW can be calculated by:

$E_l = y_l + \frac{v_l^2}{2g} = y_l + \frac{q^2}{2gy_l^2}$	(2)
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where E_l is the magnitude of energy at the downstream side of GGW (m), y_l is the depth of water at downstream side of GGW before the hydraulic jump, and v_l is the velocity of flow at the downstream side of GGW (m/s). The difference in energy between the upstream and downstream sides of GGW, ΔE , may be calculated by:

$\Delta E = E_u - E_l$	(3)
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Results of Representation of Energy Dissipation in GGW:-

Previous researchers have used different relations to represent the dissipated energy in hydraulic structures by developing empirical equations for hydraulic jump as criterion of energy dissipation [1], [10], [11], [19], [22], and [23]. The present paper aims to view the direct relationship between ΔE , and the distance of hydraulic jump, DHJ, formed away. From downstream toe of GGW, as criterions for representation of energy dissipation.



Fig. 1:- A photo of GGW.No.1 with G.S.No.1.

Figures 2, 3, 4, 5, and 6 show the relationship above for five different lengths of GGW used in this paper. These figures show that the best form of equation of trend line which represents the relationship ΔE - DHJ was the exponential form for Figs. 2, 3, 4, and 5, and the multi linear for Fig. 6 by using "Microsoft – Excel" computer program as in (4) and (5) below :

$DHJ = c_1 e^{c_2 \Delta E}$	(4)
$DHJ = h_1 \Delta E^2 + h_2 \Delta E + h_3$	(5)

where c_1 , c_2 , h_1 , h_2 , and h_3 are coefficients. Table I presents the values of coefficients c_1 , c_2 , h_1 , h_2 , and h_3 . Generally, for all figures, ΔE values are directly proportional with DHJ values. This behavior comes from transforming of the potential energy at the upstream side of GGW to kinetic energy at its downstream side, which causes to increase the distance of formation of hydraulic jump from the toe of GGW. Fig. 2 shows that increasing of both values of ΔE and diameter of gravel sample used d has no arresting effect on the DHJ value at the minimum and medium value of ΔE , and that appears clearly by noticing the intersection and approach of trend lines from each other for G.S.No.2, 3, 4, and 5 till it gets ΔE equal to 0.175 m, where the diverge in trend lines starts noticeably after ΔE equal to 0.210 m, which refer to start the increasing in values of DHJ directly with increasing both values of ΔE and d . Fig. 3 explain that the trend lines approach for each other for minimum values of ΔE , which refer to approach of DHJ values for all gravel samples at these values, but this approach disappears by the diverge of trend lines with increasing both values of ΔE and DHJ. Increasing of d value shows undular effect on both criterions. Fig. 4 shows that the approach of DHJ values from each other for different gravel samples at the minimum values of ΔE by noticing the intersection and approach of trend lines from each other for these values. The gradation of gravel samples appears clearly on both G.S.No.1 and G.S.No.2, where values of DHJ decrease by increasing both values of d and ΔE , but the gradation has no clear effect on the last three gravel samples, G.S.No.3, 4, and 5, and the trend lines show the limited effect of increasing in ΔE values on values of DHJ. Fig. 5, as in figures above, illustrates that the approach of trend lines from each other is clear which refers to approach of DHJ values from each other for minimum values of ΔE , and the clearance of intersection of trend lines at these values. The values of DHJ increases by increasing of

ΔE values and decreasing of d values. Fig. 6 shows that the behavior of trend lines at minimum values of ΔE is as in figures above for the last three gravel samples, G.S.No.3, 4, and 5. The values of DHJ for G.S.No.1 and G.S.No.2 increase by increasing of ΔE values noticeably. The effect of increasing of ΔE values on DHJ values is light for minimum and medium values of ΔE , but it becomes good and clear for high values of ΔE . All these variations happen with decreasing of d value. To identify the effect of both of applied discharge and d precisely on both values of ΔE and DHJ, three values of applied discharge were chosen for every gravel sample used, and their values were the minimum value of discharge, ($q_{min} = 0.7$ l/s), the comparison value of discharge, ($q_{cmp} = 3.6$ l/s), and the maximum value of discharge measured within the series of test runs that carried out on each gravel sample, (q_{max}). Table II presents the values of both of ΔE and DHJ for the chosen values of applied discharge, gravel samples, and lengths of GGW. For GGW.No.1, the hydraulic jump approaches toward the toe of GGW for the three values of applied discharge, (q_{min} , q_{cmp} , and q_{max}), as the value of d starts to increase, while the value of ΔE decreases. For GGW.No.2, the hydraulic jump approaches, (for all values of d), from the toe of GGW, (but with a little difference between values of hydraulic jump), at the q_{min} , and this approach appears clearly at q_{cmp} , the approach starts to fluctuate within a range of (1.35 – 1.565) m for q_{max} with increasing d values. For GGW.No.3, the gradation of d has no effect on the value of DHJ at q_{min} , while at q_{cmp} the hydraulic jump starts to approach toward the toe of GGW with increasing of d with noticing that the values of DHJ for the last three values of d lies in a short range, (in other word the effect of gradation starts to vanish at this range). For q_{max} , the value of DHJ fluctuates with increasing of value of d . All the changes which were happened in GGW.No.3 continue to include GGW.No.4. for both criterions. For GGW.No5 and q_{min} , there is no existence of the hydraulic jump for all d values, but the hydraulic jump starts to appear at q_{cmp} where it approaches to the toe of GGW as the value of d decreases, and this effect appears regularly at q_{max} . The value of ΔE decreases at both q_{min} and q_{cmp} , but fluctuates at q_{max} with increasing of value of d for GGW.No.2, 3, and 4 respectively. While the ΔE measured at q_{min} for GGW.No.5 shows a fluctuation in their values, but this fluctuation disappears at both q_{cmp} and q_{max} , where the value of ΔE starts to decrease by increasing of the value of d .

Dimensional Analysis:-

In general, energy dissipation of the flow passing through and over GGW depends on hydraulic and geometric variables. For rectangular shape of GGW, these variables can be functionally expressed as:

$f\{q, y_w, y_1, y_2, LT, d, DHJ, S_f, \rho, g\} = 0$	(6)
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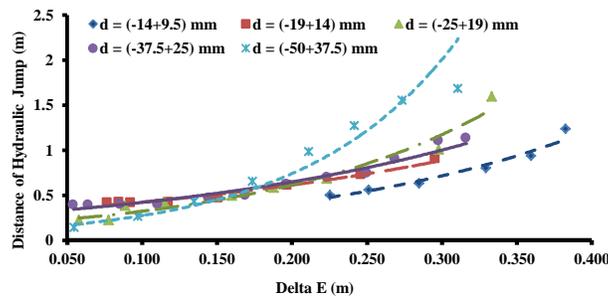


Fig. 2:- DHJ- ΔE relationship for GGW.No.1

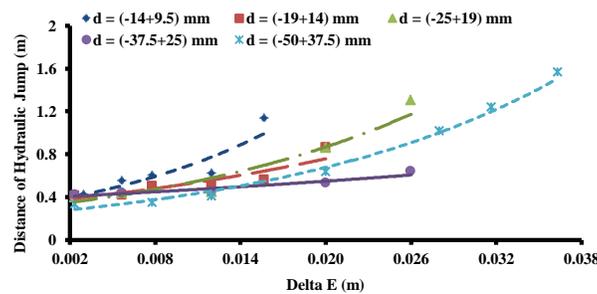


Fig. 3:- DHJ- ΔE relationship for GGW.No.2.

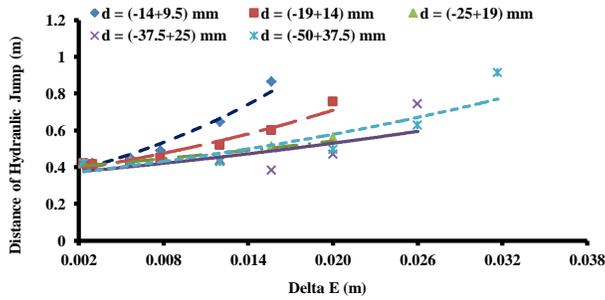


Fig. 4:- DHJ-ΔE relationship for GW.No.3.

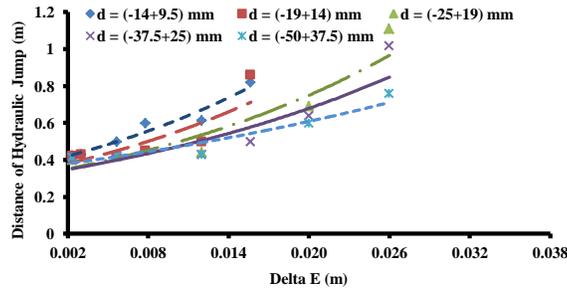


Fig. 5:- DHJ-ΔE relationship for GW.No.4.

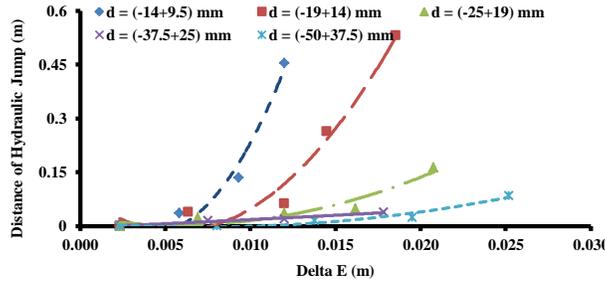


Fig. 6:- DHJ-ΔE relationship

Table I:- Values of coefficients c_1 , c_2 , h_1 , h_2 , and h_3 of DHJ-ΔE relationship.

LT (cm)	d (mm)	c_1	c_2	-	R^2
40	9.5-14	0.14	5.434	-	0.965
	14-19	0.293	3.681	-	0.968
	19-25	0.168	6.457	-	0.945
	25-37.5	0.271	4.349	-	0.957
	37.5-50	0.100	9.968	-	0.964
60	9.5-14	0.342	69.36	-	0.943
	14-19	0.355	37.94	-	0.865
	19-25	0.316	50.42	-	0.915
	25-37.5	0.394	16.59	-	0.912
	37.5-50	0.255	48.83	-	0.979
80	9.5-14	0.345	54.60	-	0.960
	14-19	0.364	33.33	-	0.948
	19-25	0.391	16.12	-	0.866
	25-37.5	0.360	19.19	-	0.515
	37.5-50	0.354	24.50	-	0.831
100	9.5-14	0.382	46.75	-	0.948

	14-19	0.346	46.08	-	0.749
	19-25	0.322	42.16	-	0.897
	25-37.5	0.322	37.18	-	0.840
	37.5-50	0.360	26.19	-	0.898
120		h₁	h₂	h₃	R²
	9.5-14	7663	-65.82	0.123	0.973
	14-19	3241	-36.43	0.088	0.966
	19-25	649.9	-7.410	0.024	0.913
	25-37.5	15.81	2.028	-0.003	0.977
	37.5-50	253.6	-3.592	0.009	0.953

where y_2 is the depth of water at the downstream side of GGW after the hydraulic jump (m), LT is the length of GGW (m), S_f is the shape factor, and ρ the mass density (kg/m^3). The shape factor can be computed from:

$$S_f = \frac{n_3}{\sqrt{n_1 * n_2}} \tag{7}$$

where n_1 , n_2 , and n_3 are the longest, medium, and shortest dimensions of gravel particles respectively. From (1), (2), and (3), its notice that E_u depends on Z_u and y_u , Z_u depends on the slope of the laboratory flume which is fixed, and E_l depends on y_l . So, (6) can be re-written as

$$f\{q, \Delta E, LT, d, DHJ, S_f, \rho, g\} = 0 \tag{8}$$

Using of Buckingham Pi – Theorem consider as an effective way to represent the relationships of parameters functionally in dimensionless mode, [2], [13], and [17]. The representation of energy dissipation by the hydraulic jump can be expressed as non-dimensional parameters as follows:

$$\frac{DHJ}{d} = f\left\{\frac{\Delta E}{d}, \frac{q}{\sqrt{g} * d^{1.5}}, \frac{LT}{d}, S_f\right\} \tag{9}$$

Table II:- Values of ΔE , DHJ, q, and d for GGW.No.1, 2, 3, 4, and 5.

Criterion	d (mm)	Discharge (l/s)		
		0.7	3.6	q_{max}
DHJ (m) for GGW.No.1	9.5-14	0.500	1.585	3.000
	14-19	0.417	0.610	2.200
	19-25	0.220	0.490	1.765
	25-37.5	0.390	0.470	1.720
	37.5-50	0.140	0.430	1.710
ΔE (m) for GGW.No.1	9.5-14	0.225	0.397	0.406
	14-19	0.077	0.197	0.374
	19-25	0.058	0.160	0.357
	25-37.5	0.054	0.144	0.345
	37.5-50	0.055	0.135	0.338
DHJ (m) for GGW.No.2	9.5-14	0.400	0.620	1.405
	14-19	0.415	0.530	1.445
	19-25	0.400	0.450	1.350
	25-37.5	0.425	0.450	1.425
	37.5-50	0.335	0.410	1.565
ΔE (m) for GGW.No.2	9.5-14	0.107	0.285	0.371
	14-19	0.088	0.235	0.378
	19-25	0.069	0.184	0.386
	25-37.5	0.064	0.165	0.375
	37.5-50	0.051	0.134	0.334
DHJ (m) for GGW.No.3	9.5-14	0.415	0.645	1.150
	14-19	0.420	0.520	0.755
	19-25	0.420	0.440	0.755

	25-37.5	0.415	0.440	1.200
	37.5-50	0.420	0.430	1.360
ΔE (m) for GGW.No.3	9.5-14	0.095	0.267	0.377
	14-19	0.071	0.236	0.350
	19-25	0.074	0.215	0.354
	25-37.5	0.069	0.179	0.364
	37.5-50	0.064	0.163	0.360
	DHJ (m) for GGW.No.4	9.5-14	0.425	0.615
14-19		0.420	0.500	1.400
19-25		0.400	0.440	1.720
25-37.5		0.400	0.430	1.61
37.5-50		0.415	0.430	1.330
ΔE (m) for GGW.No.4		9.5-14	0.119	0.331
	14-19	0.095	0.275	0.394
	19-25	0.077	0.230	0.392
	25-37.5	0.068	0.195	0.383
	37.5-50	0.066	0.169	0.357
	DHJ (m) for GGW.No.5	9.5-14	zero	0.455
14-19		zero	0.062	1.166
19-25		zero	0.035	0.740
25-37.5		zero	0.020	0.635
37.5-50		zero	zero	0.265
ΔE (m) for GGW.No.5		9.5-14	0.094	0.311
	14-19	0.103	0.291	0.374
	19-25	0.049	0.261	0.389
	25-37.5	0.054	0.223	0.365
	37.5-50	0.024	0.181	0.346

In order to represent the relationship between the dimensionless parameters above for every single value of length of GGW, the dimensionless parameter $\frac{LT}{d}$ should be eliminated. The term $(\frac{q}{\sqrt{g} \cdot d^{1.5}})$ can be written as $(\frac{Fr_g \cdot y_u}{d})$ where Fr_g represents Froude Number of gravel used. Equation (8) will become

$$\frac{DHJ}{d} = f \left\{ \frac{\Delta E}{d}, Fr_g, \frac{y_u}{d}, S_f \right\} \tag{10}$$

By using of multi-linear regression for the data set to correlate the dependent parameters with other independent ones, [14] and [21], the resulted formula can expressed by:

$$DHJ = K_1 \cdot \Delta E^{K_2} \cdot Fr_g^{K_3} \cdot y_u^{K_4} \cdot d^{K_5} \cdot S_f^{K_6} \tag{11}$$

where $K_1, K_2, K_3, K_4, K_5,$ and K_6 are coefficients depending on d . Table III presents the values of K coefficients that used in (11).

Table III:- Values of K coefficients.

K constants	Length of GGW (cm)				
	40	60	80	100	120
K₁	6.4779	1.9656	0.8936	6.3706	464.80
K₂	0.7358	0.9343	1.3548	0.6780	-1.8231
K₃	0.2515	-0.1052	-0.5151	0.0689	3.8037
K₄	0.2515	-0.1052	-0.5151	0.0689	3.8037
K₅	0.0127	0.1709	0.1603	0.2531	-0.9806
K₆	0.0264	1.0197	0.5734	-2.0914	-2.0914
R²	0.905	0.853	0.803	0.812	0.950

Conclusion:-

The study of relationships that combine parameters of flow through and over weir with porous body are generally complicated and choice of parameters that represent any phenomena like energy dissipation is important to get an acceptable numerical expression. The goals of the study may be conclude as:-

1. The difference in energy, ΔE , between upstream and downstream sides of gravel gabion weir, GGW, is directly proportional with increasing of distance of formation of hydraulic jump, DHJ, away from the weir toe in general.
2. The oscillatory effect of diameter of gravel sample used, d , appears clearly with increasing of length of the gabion weir, LT, where it is directly proportional with increasing of values of both of ΔE and DHJ for small length, (LT = 40 cm), while fluctuates with transition from small to medium lengths, (LT = 60 cm), and returns to proportion inversely with increasing of values of both criteria for medium and large lengths.
3. At the minimum value of applied discharge, q_{min} , the effect of gradation of d appears clearly on the value of DHJ for the small length, where DHJ approaches to the weir toe as the value of d increases, after that the gradation has a light effect for the medium length, (LT = 60 cm), where the values of DHJ approaches from each other within a short range, and then the gradation effect is gradually decreasing noticeably at the forth length, (LT = 100 cm), till it disappears at the large length, (LT = 120 cm). Therefore, there is no formation to the hydraulic jump for all gravel samples.
4. At the comparison value of applied discharge, q_{cmpr} , the effect of gradation of d is clear on DHJ values for all lengths, where DHJ approaches from the toe of GGW as the value of d increases, but this effect starts to be less for the last three samples of gravel used and for the last three lengths DHJ values approaches from each other within a short range.
5. At the maximum value of discharge applied within every series of test runs, q_{max} , the gradation of d on DHJ appears clearly for small lengths where the hydraulic jump approaches to the toe of GGW with increasing of value of d , while the gradation oscillates for the medium lengths, and then its effect returns to appear for large length as in small length.
6. At q_{min} , the value of ΔE decreases by increasing of d value for both small and medium lengths, and fluctuates for large length.
7. At q_{cmpr} , the value of ΔE decreases by increasing of d value for all lengths.
8. At q_{max} , the value of ΔE decreases by increasing of both of d and q_{max} values for small length and fluctuates for both parameters and medium lengths, and then returns to take the same behavior of small length for large length.

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