EFFICIENT PERFORMANCE OF COMPOUND GATES IN FLOW ENERGY DISSIPATION

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Ahmed A.A. Alkattan[1*], Bahzad M.A. Noori[2], Mwafaq Y.M. Aljburi[3]

[1]Dams and Water Resources Engineering Department, College of Engineering, University of Mosul, Iraq
[2]Civil Department, College of Engineering, Douhok University, Iraq
[3]Dams and Water Resources Engineering Department, College of Engineering, Mosul University, Iraq

ABSTRACT:
A study was conducted to evaluate the performance of compound gates in flow energy dissipation using a two-tiered structure (15 and 30 cm high). Four heights of the lower opening of the structure (0, 1, 2, 3 cm) were used, and seven values of flow depth over the edge of the structure (2, 3, 4, 5, 6, 7, 8 cm) were used for each case. The study concluded that the efficiency of compound gates in dissipating flow energy decreases with increasing flow depth over the edge of the structure. However, this performance increases in hydraulic structures with high elevations, especially when the height of the opening under those gates is increased, provided that the flow depth over the edge of these structures is constant. Compound gates are considered effective energy dissipaters for low-elevation structures if the opening under the gate is small.

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1. INTRODUCTION

The energy of water flow in open channels can be distorted due to hydraulic structures obstructing the flow. To maintain the shape of the channel section, the flow energy needs to be dissipated at the back of the hydraulic structure. Several studies have been conducted to find ways to dissipate this energy. The dissipation of flow energy has been a significant study area for researchers. They have conducted numerous experiments using various methods to dissipate this energy, such as increasing the roughness of the bottom of the channel, grading the back of the origin, placing cut-off brake blocks in the stilling basins, and using graduated weirs. Research has also been conducted on using stepped weirs with circular steps, broad crested weirs, inclined rough channel bottoms, and composite structures. Irzouki and Bakir [1] approved using cut-off brake blocks in the stilling basins, achieving a dissipation of flow energy by 80% and reducing the length of the hydraulic jump at the back of the structure to 37.5%.

Al-Qattan [2] discussed the characteristics of the flow at the back of the multi-slot scavenging gate. The researchers AL-Talib and AL-Majeed Hayawi [3] studied the dissipation of flow energy using graduated weirs. They concluded that the percentage of flow energy dissipation increases with the height of the weir relative to the critical water depth above it. However, that percentage decreases at high drainages. They also studied the effect of the hydraulic jump on flow energy dissipation [3]. Hussein et al. [4] conducted a study on the characteristics of flow and the dissipation of flow energy on a one-degree wide-rim immersion dam. The research concluded that the discharge coefficient for this type of immersion dam was 4% greater than that of a traditional wide-rim immersion dam. They also found a suitable location for the dam. Special equations were developed to measure the flow energy at the front of the weir and calculate the weir's flow energy dissipation ratio [4].

*CONTACT : Ahmed A.A. Alkattan, e-mail: ahmed.abdal-hameed@uomosul.edu.iq

Proust et al. [5] conducted a study on the dissipation of flow energy in complex channels. They discussed theoretical concepts and also explored field cases like floods in valleys with variable width [5]. The study by Al-Hashemi et al. [6] concerned the effect of the slope of the channel bottom on the amount of flow energy dissipation in the presence of a broad crested weir. The study showed that the dissipation of flow energy can be increased if the broad crested weir is made to have one runway than in its standard case [6]. Al-Talib et al. [7] conducted a study on the hydraulic jump on graded weirs and its impact on the dissipation of flow energy. The study concluded that the energy dissipation increases at hydraulic jumps forming downstream stepped weirs when the Froude number and hydraulic jump length increase. Conversely, energy dissipation decreases when (y_1/y_2) is increased. Additionally, increasing the stepped weir slope and step number leads to an increase in energy dissipation. On the other hand, decreasing weir height leads to an increase in energy dissipation [7].

The study by researchers Hussein and Jalil [8] concerned the hydraulic performance of flow in canals open in the presence of a composite structure (weir and sweep gate). Moran et al. [9] discovered that using side water jets on stilling basins can effectively dissipate flow energy by taking advantage of the flow collision. They concluded that adopting lateral flow is an effective method for this purpose. Hamid and Mohammed [10] conducted a study on the flow characteristics at the back of the multi-slot scavenging gate. It was concluded that the discharge coefficient (*Cd*) is affected by the expansion ratio (*e*). The *Cd* value increases as the *e* value increases for different water levels upstream of the gate. The contraction coefficient (*Cc*) was greatest when the expansion ratio was at its highest value and had a minimum Froude number. The *Cc* value is affected by the average flow velocity at the gates. Additionally, both the discharge and contraction coefficients decrease with increasing depth upstream of the gate and Froude number [10].

Laishram et al. [11] actively studied the effectiveness of the rough channel bottom in dissipating energy through the hydraulic jump, concluding that the inclined rough channel bottom is effective in dissipating flow energy at the back of the scavenging gate. Salim and Mohammed [12] conducted a study on flow energy dissipation in the presence of graduated weirs with rounded edges, discovering that flow energy dissipation increases as the height of the weir increases. The highest percentage of dissipation occurs at height P = 60. The diameter of the steps also affects how much flow energy dissipates, with a diameter of *D*=7.5 cm resulting in the largest percentage of flow energy dissipation. Additionally, the percentage of energy lost by the flow increases as the number of steps increases. The height of the weir and the diameter of the steps determine the number of steps.

Each diameter has a specific number of steps. Changing the geometry of the steps leads to an increase in the percentage of flow energy dissipation, such as with circular steps cut in half (F_c *and* H_c), which are better than circular steps without cutting (F_c). The geometry of all steps of the weir cut in half (H_c) is better than the two shapes. For all diameters adopted in the study, the percentage of flow energy dissipation is higher with increased discharge (*Q*), but it decreases with an increase in the Froude number (Fr_1). Stepped cylindrical weirs are better than traditional stepped weirs regarding flow energy dissipation by about 10%. The highest percentage of flow energy dissipation occurs with stepped cylindrical weirs (67.27%) compared to traditional stepped weirs (57.84%) [12].

Farzin and John [13] discussed the effect of changing the inclination of the degrees of the weir on the amount of flow energy dissipation. Awad [14] studied the dissipation of flow energy in the presence of a weir installed over a circular space. Lastly, Ikinciogullari [15] studied the dissipation of flow energy using a stepped weir with concave degrees. The research dealt with the use of different diameters to concave the degrees of the weir and the effect of that on the amount of dissipation of that energy [15].

2. MATERIAL AND METHODS

Two models of dams were made of wooden boards with a thickness of (15 mm) and a width of (81 cm), i.e. the width of the section of the concrete channel and a height (*P*) of 15 and 30 cm. The structures used were sharp-edged (Sharp Crested Weir) with a crest width equal to (2 mm) and their edges slope at an angle (60°) with the horizon according to British specifications (British Standard Institution, 1965). Metal bases are attached to the side walls of a concrete channel. Structures can slide inside these bases to move gates up and down. These gates have multiple openings at different heights, allowing the weir to function as a compound gate, Figs. 1 and 2.

These wooden boards slide inside a metal base fixed to the side walls of the concrete channel to ensure the movement of the gates up and down, and from there, an opening is obtained at the bottom of the gate at multiple heights, namely 1, 2 and 3 cm. As in Figs. 1 and 2, the channel in which the experiments were conducted was constructed of concrete, with a length of (24.64 m), a width of (0.81 m), and a depth of (0.76 m). A railway was fixed on the walls of the concrete channel to facilitate the movement of the gauges along the canal. The channel is preceded by a feeding basin with a width of 2.25 m, followed by a calming basin with a width of 3 m to ensure calm and regular flow over the structure during the experiments. Seven values for the flow depth over the structure (h') were recorded and organized in Table 1.

Table 1. Laboratory Experiment Program

Expt. No.	P (cm)	Type of hydraulic structure	Y (cm)	h' (cm)
1-7	15	Weir	0	7
8-14		Combined gate	1	7
15-21			2	7
22-29			3	7
30-36	30	Weir	0	7
37-42		Combined gate	1	6
43-48			2	6
49-52			3	4

The marks shown in Table 1 are:

h' - height of flow above the edge of the Structure (L),

P - height of Structure (L),

Y - The height of the opening at the bottom of the compound gate (L).

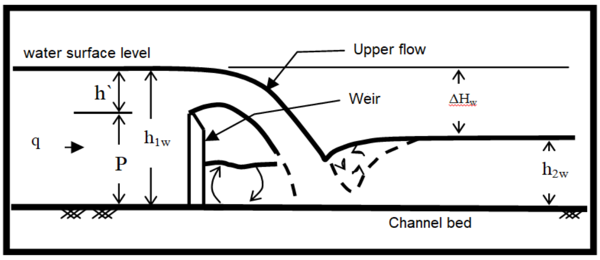

Fig. 1. Channel section with weir

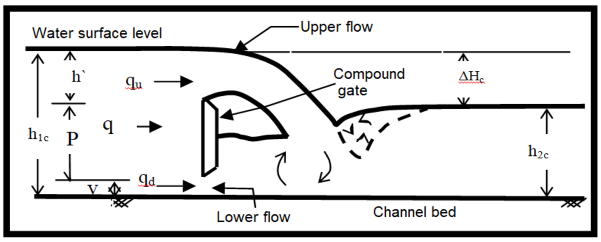

Fig. 2. Channel section With compound gate

The markings given in Figs. 1 and 2 are as follows:

h_{1w} - depth of flow in front of the weir (L),

h_{2w} - depth of flow at the back of the weir (L),

ΔH_w - the difference in the flow level at the front and back of the weir (L),

h_{1c} - depth of flow upstream of the compound gate (L),

h_{2c} - depth of flow at the back of the compound gate (L),

ΔH_c - The difference in the flow level at the front and back of the compound gate (L),

Q - channel discharge (L^3/T),

q_u - The discharge passing above the compound gate (L^3/T),

q_d - the discharge passing under the compound gate (L^3/T).

For research purposes, the flow energy was calculated using Eq. 1:

$$E = h + \frac{V^2}{2g} \tag{1}$$

where are:

h - depth of water up or downstream the structure (L),

g - ground acceleration (L/T^2),

V - velocity of flow up or downstream of the structure (L/T).

A total of fifty-two laboratory experiments were conducted, which started by attaching the weir at a height of 15 cm to the bottom of the canal. Then, turning on the pump to pass the water into the canal, and after some time, when the flow stabilized (steady flow) over the origin while maintaining the air gap formed immediately after the origin, it was done using a flow depth gauge. The point gauge measured the depth of flow at a distance of 120 cm in front of the structure and 400 cm in its rear, in addition to calculating the amount of drainage using a volumetric method for each depth. Then, the weir was raised to form an opening at the bottom and on the width of the channel at a height of 1 cm so that the weir would act like a compound gate. The flow passed in front of the structure above and below. In the exact measurement, the flow depth in the front and behind the structure was measured for the same value of the flow discharge. Then, the structure was raised to make the height of the opening at the bottom 2 cm and 3 cm, respectively, so that the structure was replaced with another with a height of 30 cm so that the same experiments above could be repeated on it.

3. RESULT AND DISCUSSION

The results presented in Tables 2 and 3 display the data obtained for the compound weir and gates. The data includes all bottom opening heights and the two frame heights from 15 cm and 30 cm.

Table 2. Experiment data for hydraulic structure (P= 15 cm)

Type	*q* (m^3/s/ unit width)	*Y* (cm)	*h'* (cm)	h_1 (cm)	h_2 (cm)
Weir	0.0295	0	2	17	3
	0.0348		3	18	3.8
	0.0435		4	19	4.5
	0.0519		5	20	5.1
	0.0617		6	21	5.9
	0.0712		7	22	6.1
	0.0795		8	23	6.7
Compound Gate	0.0491	1	2	18	6.1
	0.0531		3	19	7
	0.0597		4	20	7.9
	0.0679		5	21	8.9
	0.0762		6	22	9.7
	0.0849		7	23	10.8
	0.095		8	24	11.6
	0.0583	2	2	19	7
	0.0631		3	20	8
	0.0705		4	21	8.9
	0.0783		5	22	9.7
	0.0858		6	23	10.5
	0.0934		7	24	11.5
	0.1018		8	25	12.1
	0.0746	3	2	20	9.3
	0.0808		3	21	9.9
	0.0875		4	22	10.3
	0.0941		5	23	11.4
	0.1006		6	24	12
	0.1093		7	25	12.7
	0.1188		8	26	13.6

Table 3. Experiment data for hydraulic structure (P= 30 cm)

Type	*q* (m^3/s/unit width)	*Y* (cm)	*h'* (cm)	h_1 (cm)	h_2 (cm)
Weir	0.0295	0	2	32	3
	0.0348		3	33	3.8
	0.0435		4	34	4.5
	0.0519		5	35	5.1
	0.0617		6	36	5.9
	0.0712		7	37	6.1
	0.0795		8	38	6.7
Compound Gate	0.0491	1	2	33	6.1
	0.0531		3	34	7
	0.0597		4	35	7.9
	0.0679		5	36	8.9
	0.0762		6	37	9.7
	0.0849		7	38	10.8
	0.0583	2	2	34	7
	0.0631		3	35	8
	0.0705		4	36	8.9
	0.0783		5	37	9.7
	0.0858		6	38	10.5
	0.0934		7	39	11.5
	0.0746	3	2	35	9.3
	0.0808		3	36	9.9
	0.0875		4	37	10.3
	0.0941		5	38	11.4

Tables 4 and 5 show the calculations of the percentage difference in flow energy at the front and back of the structure to the energy at the front of it (ΔE).

The marks shown in Tables 4 and 5 are:

E_{1w} - the energy of flow upstream weir (L),

E_{2w} - the energy of flow downstream weir (L),

E_{1c} - the energy of flow presented to the compound gate (L),

E_{2c} - flow energy at the back of the compound gate (L),

ΔE % **-** The percentage of difference in flow energy at the front and back of the structure to the energy at the front of it (Unit less).

Table 4. Energy up, downstream the structure and energy dissipation (P= 15 cm)

Type	*Y* (cm)	E_{1w} (m)	E_{2w} (m)	*ΔE*	*ΔE* %
Weir	0	0.1715	0.0793	0.0923	53.8
		0.1819	0.0807	0.1012	55.6
		0.1927	0.0926	0.1	51.9
		0.2034	0.1038	0.0996	49
		0.2144	0.1147	0.0997	46.5
		0.2253	0.1304	0.0949	42.1
		0.2361	0.1388	0.0973	41.2
Compound Gate	1	0.1838	0.094	0.0898	48.8
		0.1940	0.0993	0.0947	48.8
		0.2045	0.1081	0.0964	47.1
		0.2153	0.1187	0.0967	44.9
		0.2261	0.1285	0.0977	43.2
		0.2369	0.1395	0.0974	41.1
		0.2480	0.1502	0.0978	39.4
	2	0.1948	0.1054	0.0894	45.9
		0.2051	0.1117	0.0934	45.5
		0.2157	0.1210	0.0948	43.9
		0.2265	0.1302	0.0962	42.5
		0.2371	0.1390	0.0981	41.4
		0.2479	0.1493	0.0986	39.8
		0.2585	0.1571	0.1014	39.2
	3	0.2071	0.1279	0.0792	38.2
		0.2175	0.132	0.0856	39.3
		0.2281	0.1383	0.0989	39.4
		0.2385	0.145	0.0936	39.2
		0.2490	0.1518	0.0972	39
		0.2597	0.161	0.0987	38
		0.2706	0.1701	0.1005	37.1

Table 5. Energy up, downstream the structure and energy dissipation (P= 30 cm)

Type	*Y* (cm)	E_{1c} (m)	E_{2c} (m)	*ΔE*	*ΔE %*
Weir	0	0.3693	0.037	0.3323	89.99
		0.3727	0.0451	0.3277	87.91
		0.3876	0.0527	0.335	86.42
		0.4028	0.0593	0.3435	85.29
		0.4157	0.0678	0.3479	83.69
		0.4394	0.0708	0.3686	83.88
		0.4518	0.0774	0.3744	82.87
Compound Gate	1	0.3630	0.0677	0.2853	81.35
		0.3693	0.077	0.2924	79.16
		0.3791	0.0863	0.2928	77.23
		0.3897	0.0967	0.2929	75.17
		0.4015	0.1052	0.2962	73.79
		0.4115	0.1166	0.2949	71.66
	2	0.3754	0.0772	0.2982	79.44
		0.3817	0.0874	0.2943	77.1
		0.392	0.0968	0.2952	75.3
		0.4032	0.1053	0.2979	73.89
		0.414	0.1137	0.3003	72.53
		0.4243	0.1242	0.3001	70.73
	3	0.4079	0.0785	0.3294	80.76
		0.412	0.0887	0.3233	78.48
		0.4193	0.098	0.3213	76.64
		0.428	0.1063	0.3216	75.15

On Figs. 3 and 4 show the relationship of the flow energy dissipation ratio (*ΔE*) with the ratio of the flow height over the edge of the structure to its height (*h'/P*) for the cases of the weir and the compound gate for three heights of the opening at the bottom of the gate and for two heights of the structure, 15 and 30 cm. Figs. 3 and 4 show (*ΔE*) and (*h'/P*), that is, the percentage of flow energy dissipation decreases in the presence of flow at the bottom of the structure, especially in the case of a small elevation, because the collision of the upper flow with the lower flow increases the flow energy at the back of the structure, and thus the percentage decreases. Energy dissipation means that the performance efficiency of the installed gates in dissipating energy is weak. At the same time, the matter begins to reverse in the case of a greater height of the structure, as in Fig. 4. The effect of the bottom flow and in the case of increasing the height of the lower opening, increases the percentage of energy dissipation, meaning that the efficiency. The performance of the composite gate in dissipating flow energy begins to improve provided that the flow depth above the edge of the origin remains constant.

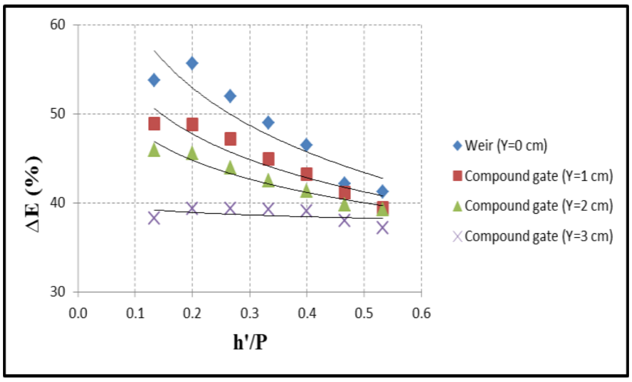

Fig. 3. Relation between ΔE (%) and (h'/P) for structure of height (P=15 cm)

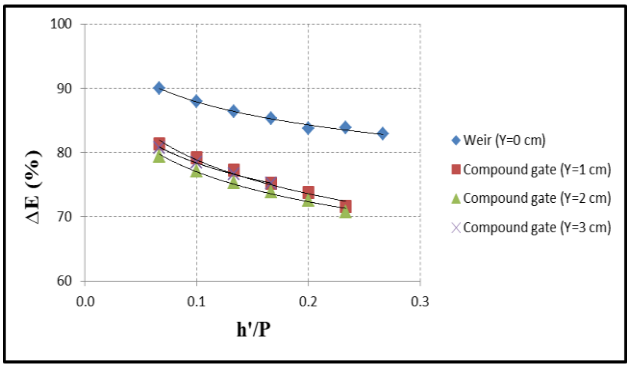

Fig. 4. Relation between ΔE and (h'/P) for structure of height (P=30 cm)

Figs. 5 and 6 show the relationship of the flow energy dissipation ratio (*ΔE*) with (*Q*) for the weir and the compound gate cases with two structure heights of 15 and 30 cm. It is clear from the relationship *ΔE* and *Q* in Figs. 5 and 6 that the percentage of flow energy dissipation decreases as the discharge increases in the case of the composite gate compared to the weir (with a small height). The performance of the gate begins to decrease with the increase in the height of the lower opening of the composite gate, while the efficiency of the performance of the composite gate (in structures with a greater height) increases. It appears after increasing the height of the lower opening.

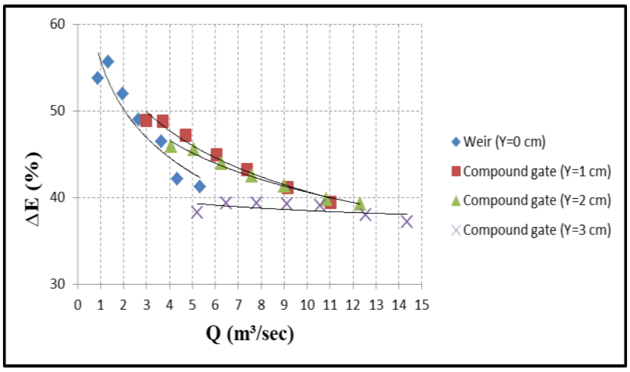

Fig. 5. Relation between ΔE and Q for structure of height (P=15 cm)

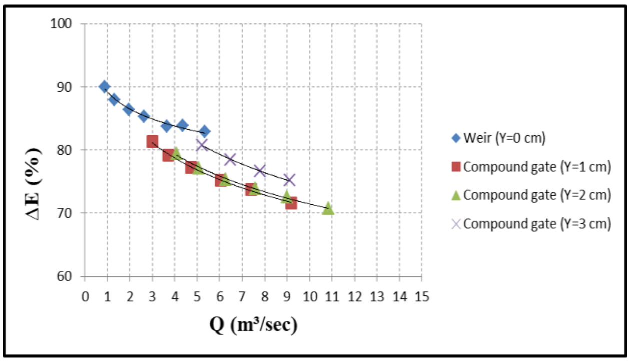

Fig. 6. Relation between ΔE and Q for structure of height (P=30 cm)

4. CONCLUSIONS

The main results of the research in this paper are as follows:

1) When the depth of the flowing water increases above the upper edge of a gate structure, the efficiency of the installed gates in dissipating flow energy decreases. This happens because the upper flow collides with the lower flow, causing the flow speed to decrease. As a result, the percentage of flow energy dissipation decreases in general.
2) The Compound gate is a useful energy dissipater for high hydraulic structures where bottom drainage increases. However, this feature starts to lose effectiveness as the height of the bottom opening increases. This is because the collision of the upper and lower flows becomes less effective in dissipating energy.
3) Compound gates are highly efficient in dissipating flow energy in hydraulic structures with high heights. Because the perpendicular distance of the fall flow is high, it leads to a Strong collision with the lower flow, which causes higher energy dissipation.

Conflicts of Interest

The authors declare no conflict of interest.

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