AN INVESTIGATION CONCERNING THE WATER ENERGY DISSIPATION AND FLOW AERATION OVER STEPPED SPILLWAYS

Mohamed A. Ashour[1],Tawab E. Aly[2], Mohamed K. Ali[3]

[1] *Professor, Civil Eng. Dept., Assiut University, Egypt, mashour475275@yahoo.com.*
[2] *Associate Prof., Civil Eng. Dept., Assiut University, Egypt, tawab_aly@yahoo.com.*
[3] *M.Sc. Student, Civil Eng. Dept., Assiut University, Egypt, mkhairy@aun.edu.eg.*

ABSTRACT

Spillways usually used for escaping water from the U.S. having a high-water level, to D.S. having a low water level in most of the diversion head structures through water streams. The D.S. of such spillways usually suffers from the destructive impacts of the generated kinetic energy of the flowing water, having a very high speed, which may cause cavitation in such spillways body. In the present work, some geometrical treatments on the back of the spillway body, are introduced for increasing its efficiency in dissipating the kinetic energy of the flowing water, having great potential energy, and improving the flowing water quality by increasing its dissolved oxygen content, through generating huge aeration at the flow in the back, in addition to prevent cavitation which may occur, and generated on the back of the spillway body. Previous studies proved that the stepped back of the spillway body is one of the most practicable trails done for achieving the above-mentioned goals. In this paper, a review of previous authors` technical methods to obtain the best design of the spillway geometric that dissipates high values of the kinetic energy and improving the flow aeration.is highlighted.

Key words: Stepped spillway, Energy dissipation, Dissolved oxygen content, Re-aeration

1 INTRODUCTION

The design and construction of spillways or stepped weirs are very complicated due to difficulties and risks such as erosion, cavitation, scour and high flow kinetic energy. The water discharging over the spillway has to fall down from a higher elevation to lower one. So, the flow has a high velocity and the potential energy is converted into a kinetic energy at the toe of spillways, therefore, the surface of the spillways should be able to dissipate this energy which causes erosion and scour downstream such structures. The back-surface roughness of spillway can be generated by adding some energy-dissipating devices, such as baffles or steps. Steps on the back surface of the spillway are the most common energy-dissipating devices. The stepped spillway design enhances the rate of energy dissipation on the spillway, thus reducing the size and the cost of the downstream stilling structure. The geometry of steps such as number of steps, angle of the back surface of the spillway, and any accessories on the step affect the efficiency of the spillway in the dissipated energy and re-aeration of the flow. Many authors studied the effect of such geometric changes on the flow over the spillways, a lot of results indicated that; the energy dissipation increases with decreasing number of steps and decreasing the angle of the back surface of the spillway (Khalaf, 2014; Al-Husseini, 2015; Irzooki, 2016; Tabari and Tavakoli, 2016), while Rad and Teimouri, 2010 and Jahad et al. ,2017 concluded an inversely result with the number of steps (N_s),they found that; with increasing the number of steps, the energy dissipation increased.

Such achievements will be through studying the most effective number of steps (N_s) and the most effective angle of the back surface of the spillway (Θ^{o}). Also, estimating the optimum value of the relative ratio between the step height (h) to the spillway height (H) i.e. (h/H). The geometrical arrangement and distribution of the step roughness over the spillway body will be tested, to know which is better; straight steps or staggered steps.

2 LITERATURE REVIEW

2.1 Flow Regimes

Flow regimes over the spillways are divided into three types, napped flow, transition flow and skimming flow **(**Alghazali and Jasim, 2014; Chanson, 1994)as indicated in figure (1).In napped flow pattern the water passes from one step to the other, developing a small hydraulic jump on every step. This jump can be observed for a small ratio of (y_c/h)(where (y_c)is the critical flow depth and (h) is the step height), The skimming flow regime is observed for the higher discharges according to Wongwises (2006), and with a large value of (y_c/h)..Khdhiri et al. (2014)stated that; with increasing step height (h),decreasing the ratio of (h/l) where (l) is the step length, with smaller flow rate, the napped flow regime can be performed. At the same time, with decreasing step height (h), increasing the relative ratio of (h/l), with higher flow rate, the skimming regime can be performed. The efficiency of spillways or stepped weirs depends on the type of flow patterns on its back surface. Chafi et al. (2010)concluded that the napped flow dissipates the kinetic energy better than the skimming flow regime. In addition to the dissipated energy, also the napped flow regime has a higher aeration efficiency than skimming flow regime owing to Baylar et al. (2006), their experimental results indicated that; napped flow depends on the number of spillway steps and the discharge, while the skimming flow regime depends on the angle of the back surface of spillway and on the discharge.

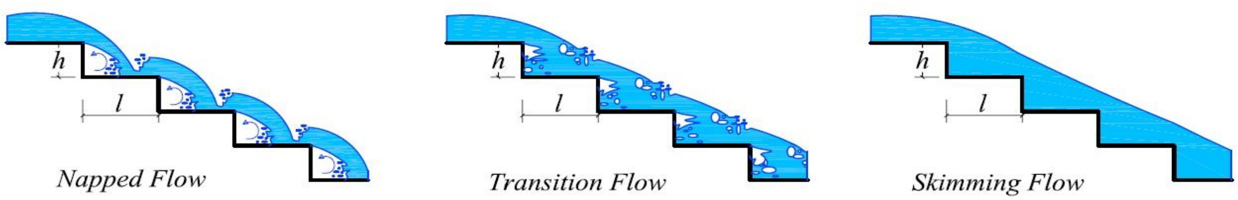


Figure1. Flow regimes overstepped spillways, (Alghazali and Jasim, 2014; Chanson, 1994)

The following constructed table shows the most popular equations that predict the limitations of flow regimes.

Table 1. Limitations of flow regimes

Author	Step geometry				y_c/h		
	Shape	Θ^0	N_s	h/l	Napped flow	Transition flow	Skimming flow
Al-Husseini (2016)	Rough	30°	4	0.43	< 0.67	0.67 : 0.98	> 0.98
Zhang & Chanson (2016)	Gabion	26.6°	10	0.50	< 0.60	0.60 : 0.90	> 0.90
Abdul-Mehdi et al. (2016)	Rough	30°	4	0.45	<0.50	0.50 : 0.71	>0.71

Alghazali & Jasim (2014)	Pooled (sills)	25°: 45°	5	0.4 7:1	=1.0674-0.212 (Θ) +5.123 (h/l)	---	$=\frac{h/l}{5.2321\Theta-0.2801}$
Guenther et al. (2013)	Flat Pooled	26.6°	10	0.5 0	< 0.50 < 0.45	0.50 : 0.90 0.45 : 0.9٧	> 0.90 > 0.97
Felder & Chanson (2013)	Flat Pooled	26.6° 8.9° 26.6° 8.9°	10 21 9 20	----- -	≤ 0.57 ≤ 0.95 < 0.45 < 1.08	0.57 : 0.90 0.95 : 1.69 0.45 : 0.9٧ 1.08 : 1.76	> 0.90 > 1.69 > 0.97 > 1.76
Zare & Doering (2012)	Sill-shifted rounded	45°	10	1.0	---	< 1.20	> 1.20

Table 1. Limitations of flow regimes (continued)

Author	**Step Geometry**				**y_c/h**		
	Shape	**Θ^0**	**N_s**	**h/l**	**Napped Flow**	**Transition Flow**	**Skimming Flow**
Chinnarasri & Wongwises (2004)	Upward inclined step (α)	30° 45° 60°	---	0.1: 1.73	= 0.927 -0.005α - 0.388 h/l	---	= (0.844 + 0.003 α) $h/l^{\,-0.153+0.004\Theta}$
Chanson & Toombes (2004)	Flat	3.4° 15.9° 21.8°	9	<1.7 <1.5	< 0.9174 - 0.381h/l ---	---	--- $>\frac{0.9821}{(\frac{h}{l}+0.388)^{0.384}}$
James et al. (2001)	Notch	24.6° 16.1° 5.5°	3 5 7 15	0·48 0·29 0·19 0·096	≤ 0.541 $(h/l)^{-1.07}$	---	> $0.541(h/l)^{-1.07}$
Chamani & Rajaratnam (1999)	Flat	---	---	=1.70 < 0.8	---	---	≥ 0.24 ≥ 0.80
Chanson (1994)	Flat	---	---	---	< 1.057 − 0.46 /	---	≥ 1.057 − 0.465 h /l

From the above constructed table, it can be noticed that, the limitation of flow regimes depends on the angle of the back surface of the spillway (θ°), and the relative ratio between the step height to the step length (h/l). The length of step needs to be relatively large for preforming the napped flow regimes. The skimming flow regime occurs for a large value of (h/l > 1.7), and for a small value of ($y_c/h \geq 0.24$).At the same conditions, except with the two different values of (h/l), owing to Abdul-Mehdi et al. (2016) and Al-Husseini (2016), The large limit of napped and skimming flow regimes occurred in the small value of (h/l). So, it is necessary in the design of the stepped spillways geometry to perform the napped flow regimes with the maximum flow rate, in order to insure high efficiency of stepped spillways in the energy dissipation and re-aeration of flow.

2.2 Effect of the Spillway Geometry on Water Energy Dissipation Efficiency.

Christodoulou (1993) studied experimentally the energy dissipation on stepped spillways, the experimental model consisted of seven steps with variable ratio between height and length of the steps of the upper curved part, followed by eight steps on the straight part with constant relative values of height to length ratio (h/l) equals 1.43. The result pointed out that the energy dissipation increases with a small value of (y_c/h), also indicated that the number of steps (N_s) was more appreciable for a higher value of(y_c/h). So, the energy dissipation increases with increasing number of steps (N_s) for a certain ratio of (y_c/h).

Wongwises (2006) studied the flow patterns and the energy dissipation on the stepped spillways. Three numbers of steps (N_s) were tested (20, 40, and 60 steps),as shown in 9th row of table (2). He concluded that; for a certain flow rate with a constant step height (h) or constant relative critical flow depth (y_c/h), the relative energy loss ($\Delta E/ E_o$) increases when the number of steps(N_s) increases.

Hunt and Kadavy (2009) investigated the effect of step height (h) on the energy dissipation in stepped spillways, two physical models were constructed on a slope 4 (H):1 (V) of the back surface of spillway, they concluded that with increasing step height (h) the energy dissipation increases.

Abbasi and Kamanbedast (2012) used models have two numbers of steps (5, 10) to investigate their effect on the energy dissipation in spillways, they pointed out that the dissipated energy increases with decreasing the number of steps (N_s).

Khalaf (2014) studied experimentally hydraulic characteristics of flow and energy dissipation over-stepped spillways. Three types of the back surface slope of the spillway (H:L=1:0.75, 1:1 and 1:125) were used with three numbers of steps (N_s= 3, 5 and 7), were used for each slope, they concluded that; increasing the roughness Froude number (F_e), number of steps (N_s), and angle of the back surface of spillway caused decreases in the energy dissipation values for all stepped models.

Al-Husseini (2015) studied experimentally the energy dissipation on stepped spillway, three angles of the back surface of spillway (θ = 27°, 32°, and 40°) were tested with stepped spillway having two and four steps. He concluded that; the energy dissipation increased with decreasing number of steps (N_s), and with decreasing the angle of the back surface of the spillway (θ). Also, the result indicated that; the stepped spillways are more efficient in flow energy dissipation compared to flat sloped spillways.

Irzooki (2016) used the computational fluid dynamics program (CFD - program Flow-3D) to analyze and study the characteristics of flow energy dissipation over-stepped spillways. Three different spillway heights (H= 15, 20 and 25cm) and different spillway lengths (L) were used. For each model, three numbers of steps (N_s= 5, 10 and 25) and three slopes of the back surface of the spillway (H: L= 1:2, 1:1 and 1.25:1were used. He concluded that the energy dissipation increased with increasing the spillway height (H), decreasing the number of steps (N_s), and decreasing the slope of the back surface of the spillway (H: L). Also, he pointed out that the energy dissipation decreases with increasing the flow rate, and the maximum energy dissipation was obtained over the model which had (H) =25 cm, (N_s) =5, and (H:L) =1:2, where it was ranged between 77%: 86 %.

Tabari and Tavakoli (2016) studied the effect of stepped spillway geometry on flow patterns and energy dissipation; three types of geometric models with (N_s) equals 10, 15, and 20 steps were used, with a constant angle of the back surface of the spillway equals 45^o. They found that the energy dissipation decreased when the flow discharge increased,while the energy dissipation decreased when the number of steps (N_s)increased.

Jahad et al. (2017) studied the effect of stepped spillways geometry on the energy dissipation, four models were used, the angle (Ɵ) of the back surface of spillway equals 26.6°, and 21.8°, and two number of steps equals 6 and 10 were experimented, as shown in 1st row of table (2). The experimental results indicated that the energy dissipation increased with increasing the step numbers (N_s) and decreasing the angle of the back surface of the spillway (Ɵ). So, in spillways with number of steps (N_s) equals 10 gives better performance than (N_s) equals 6 in energy dissipation and flow regime. Also, they stated that step's number (N_s) had a greater impact than step height (h) in low discharges.

Many authors have tried to improve the energy dissipation downstream spillways by using different shapes and with different steps geometry; the following constructed table (2) shows the most popular technical methods of pervious authors and their trails to obtain the effective steps geometry which dissipate the maximum kinetic energy downstream the stepped spillways.

Table 2. Effects of step geometry of spillways on the energy dissipation according to different authors

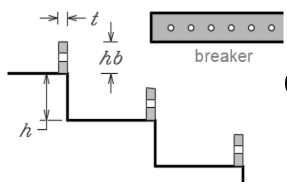
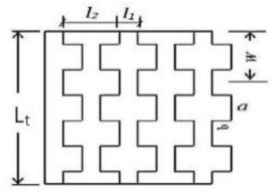
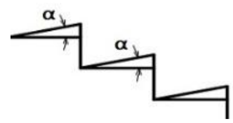
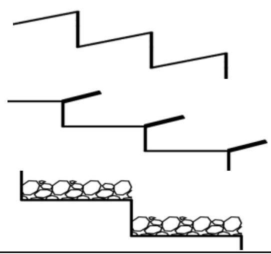
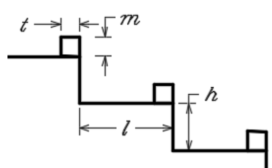
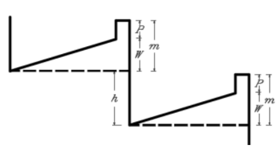
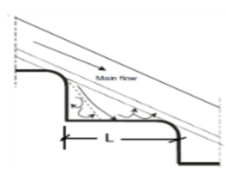
Author	Slope Angle (Θ^o)	Step Geometry	Step Shape	Energy Dissipation Efficiency	Conclusion
Aal et al. (2017)	45	- N_s= 4. h_b/h =0.2, 0.4, 0.6, 0.8 and 1. - Thickness of the end sill (t) = 2, 5 & 10 mm. - The area of holes = 2.22%, 5%, 10% & 20% of the breaker area.		67%	- The holes 5% gave the maximum ΔE, which is occurring at h_b = 0.8h, and with a three-hole area.

Table 2. Effects of step geometry of spillways on the energy dissipation according to different authors (continued)

Author	Slope Angle (Θ^o)	Step Geometry	Step Shape	Energy Dissipation Efficiency	Conclusion
Jahad et al. (2017)	21.8 26.6	- N_s = 6 and 10 - Flat steps -1/4 circular end sill		88%	- The maximum energy dissipation was obtained from the model which have N_s = 10 steps and with ¼ circular end sill.

Hussein & Jalil (2016)	45 26.6	-N_s = 5 and 10 - Two different widths of rectangular cycle (0.06 and 0.1 m).		18.7%	- The model with angle of the back surface of spillway (Θ^0) equals 26.6^0, number of steps(N_s) =5 and with a magnification length ratio (Lt/w) = 2.67, was better for dissipating energy.
Fesharaki & Mansoori (2016)	18.4	- Reverse inclined angle (α^0) = 7°, 10°, and 12°).		3.76%	- The energy dissipation increases with increasing the revers inclined angle (α^0).
Al-Husseini (2016)	30 50 70	- Plain steps, half cut, inclined end sill, and crushed with gravel.		19%	- The maximum energy dissipation occurred in the rough steps and end sills respectively, compared with plain steps.
Asadi et al. (2015)	18.4	- Height of end sills (m) 0.2, 0.3, and 0.4 times higher than the step height - Length of sills (t) 0.5, 0.25 times the length of steps.		11%	- The maximum energy dissipation occurred with the model had sills with $\frac{m}{h} = 0.4$ and with $\frac{t}{l} = 0.25$.
Hamedi et al. (2012)	45	- Inclined steps and end sill together. - Adverse slopes equal 7°, 10°, and 12°.		16.4%	- The maximum values of energy dissipation were obtained in the model with $\frac{\mathrm{m}}{\mathrm{h}}$ equal to 0.7.
Zare & Doering (2012)	45	-N_s= 10 -The rounding radius (r) was r/L = 0.25.		3%	- Steps with rounding edge dissipated energy more than sharp edges.

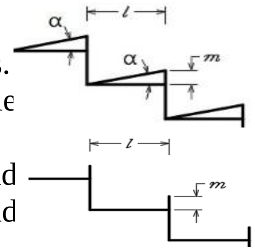
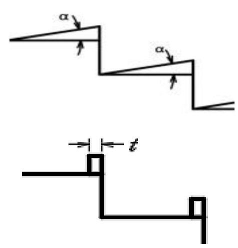
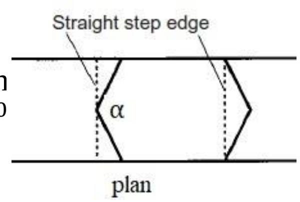
Wongwises (2006)	30 45 60	- Horizontal step. - Inclined step. - Steps with end sills. -The reverse angle (α) 10, 20, and 30°. -The height of end sill (m) 5, 10, and 15 mm.		67.6%	- Steps with end sill dissipated the kinetic energy more than inclined steps at the same height (m).

Table 2. Effects of step geometry of spillways on the energy dissipation according to different authors (continued)

Author	Slope Angle (Θ^o)	Step Geometry	Step Shape	Energy Dissipation Efficiency	Conclusion
Barani et al. (2005)	41.4	- Thickness of the end sill(t) =1, 2, 3 and 4cm, - Angle of the adverse slope to(α) 15°, 26°, 36° and 45°		---	- Steps with adverse slope can be more effective than the steps with end sills which have the same size.
James et al. (2001)	25.6 16 10.8 5.48	- N_s = (3,5,7, and 15) -The wedge/notch angle (α) 180^0, 135^0, and 90^0		---	-The energy dissipation increases with decreasing (α). -The maximum dissipated energy occurred in ($\alpha = 90^0$). -With a large step height and small angle (α), the dissipated energy increases three times than traditional stepped spillway.

From the above constructed table, the following technical points can be noticed:

- Modification in roughness steps geometry could enhance the degree of the water energy dissipation efficiency. It changed from 3% with rounded step edge (Zare and Doering, 2012), to 88 % with the quarter circular end sill (Jahad et al, 2017).
- End sill proved more efficiency than the reverse inclined angle (Wongwises, 2006).
- The steps with inclined slope proved to be more effective than the steps with end sills having the same size (Barani et al, 2005).
- It was noticed that the effective length of reverse inclined angle was not investigated yet, according to our best knowledge. So, it will be studied in the present research.

2.3 Flow Aeration over Stepped Spillways

Aeration is the process through which the air contact in the flow, exists, and so, the dissolved oxygen content can be increased, and the water quality can be improved. In this stage of the present study we will investigate the effect of new configurations on the aeration efficiency on the back-surface of spillway body, such as steps with a quarter circular end sill, steps with reverse inclined angle, and staggered arrangements of steps. Given below constructed table (3) shows the most common technical methods tested by many authors and their trails to improve the flow aeration downstream the spillway.

Table 3.Effects of step geometry of spillways on the flow aeration according to different authors

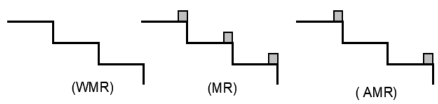
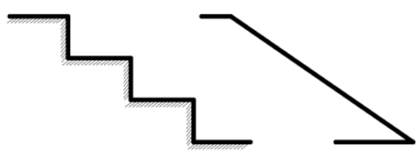
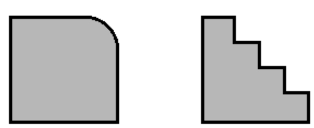
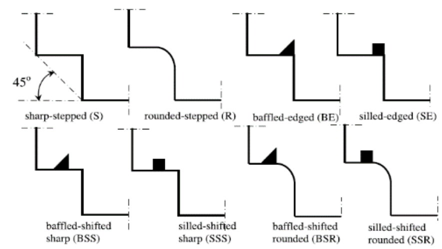
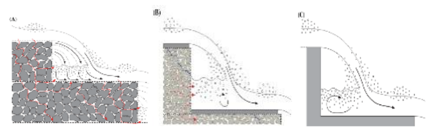
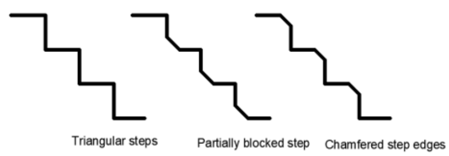
Author	Step Geometry	Step Shape	Conclusion
Kökpinar (2004)	-Without Macro Rroughness (WMR) -With Macro Rroughness on each step (MR) -With Macro Rroughness on each second step(AMR).		The AMR step increases air-concentration by 8.3% –11.1% higher than the WMR step configuration, and 17.2%–22.0% higher than the MR step configuration.

Table 3.Effects of step geometry of spillways on the flow aeration according to different authors (Continued)

Author	Step Geometry	Step Shape	Conclusion
Emiroglu & Baylar (2006)	-Slope of the smooth was 8.40°, 10.82°, and 12.94°. -Slope of steps spillway was 14.48°, 18.74° and 22.55°.		Stepped spillway aerated the flow more than smooth spillway. The aeration efficiency increases with decreasing the ratio of critical flow depth to step height (y_c/ h), and with decreasing the Froude number (F_r).
Aras & Berkun (2010)	-Smooth -Stepped spillway with 4 steps		Dissolved oxygen content and aeration efficiency along the smooth and stepped spillways increase with increasing flow rates. Aeration efficiency on the stepped spillway is higher than the smooth spillway.

Zare & Doering (2012)	-Sharp-stepped -Rounded-stepped -Baffled-edged -Silled-edged -Baffled sharp -Silled sharp -Baffled rounded -Silled rounded		The silled-shifted rounded spillway gives the smallest inception-point, so it is recommended to be used in cavitation damages mitigation
Wuthrich & Chanson (2015)	-With capping spillway -Without capping spillway -Flat impervious stepped spillway		Inlarge flow rate, the aeration efficiency of the flat impervious stepped spillway (Model C) was larger than that of the gabion stepped chute (Model A).
Zhang & Chanson (2018)	-Angle of the slope equals 45°. -Triangular steps -Chamfered steps -Partially blocked step cavities		The chamfers led to reduction in air-entrainment. The Partial cavity blockages appeared to have little effect on air-entrainment.

From the table, it can be noticed that, the dissolved oxygen content increases with decreasing Froude number and with decreasing the ratio of critical flow depth to step height (y_c/h).

3 THEORETICAL APPROACH

The relevant variables governing the energy dissipation over stepped spillway are shown in the following figure (2).

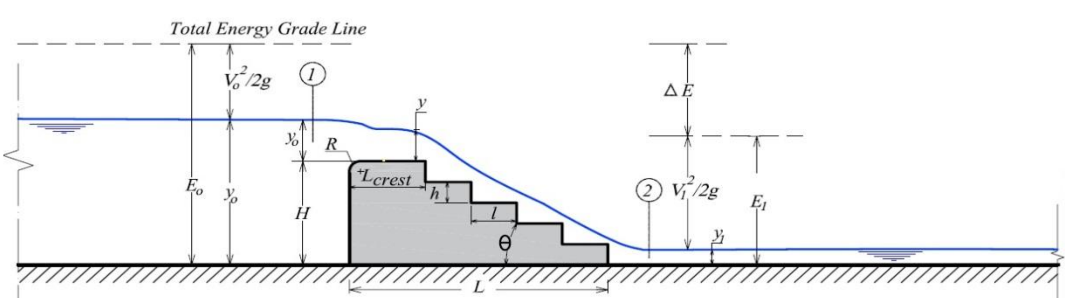


Figure 2. Definition sketch for experimental model.

Three groups of parameters effect on the stepped spillway performance in the water energy dissipation and flow aeration as follows:

1) Fluid properties

ρ : Water density;
μ: Dynamic viscosity, and
σ : Surface tension.

2) Flow characteristics

y_0 : Upstream water depth;
y_1 : Water depth just downstream the spillway;
y_2 : Tail-water depth downstream the spillway;
v_1 : Water velocity just downstream the spillway;
v_2 : Water velocity downstream the spillway;
E_o :Upstream water Energy;
ΔE: Total energy loss; and
g : Gravity acceleration.

3) Geometric properties

B : Channel width;
h : Step height;
H : Spillway height;
L : Length of spillway;
l_r : Length of reverse slope;
l : Step length;
N_s: Number of steps;
R : Radius of curvature of upstream face:
Ɵ : Angle of slope of the back surface of spillway; and
r_s : Radius of end sill.

The relationship represents the previous parameters can be written as follows:

$$Ø_1 = (\rho, \mu, y_c, y_1, y_2, h, \square, N_s, g, Eo, \Delta E, \theta, B, R) \quad (1)$$

By using Buckingham π theorem with three repeated variables $\square_c$, ρ, and v_c to derive the dimensional analysis, the outcome equation will be as follows:

$$Ø_2 = \left(\frac{y_0}{y_c}, \frac{y_1}{y_c}, \frac{h}{y_c}, \frac{l}{y_c}, \frac{B}{y_c}, \frac{\Delta E}{y_c}, \frac{\Delta E}{Eo}, \frac{v_c^2}{gy_c}, \theta, N_s, \frac{\mu}{\rho y_c v_c}, \frac{R}{y_c}\right) \quad (2)$$

Where $\frac{\mu}{\rho y_c v_c}$=1/Re and $\frac{v_c^2}{gy_c} = F_r^2$

By neglecting the effect of (Re) which has very large values i.e. the flow is fully turbulent and consequently its effect could be neglected, so the general equation could be written as follows.

$$\frac{\Delta E}{E_0} = Ø_3 \left(\frac{y_0}{y_c}, \frac{y_1}{y_c}, \frac{h}{y_c}, \frac{l}{y_c}, \frac{B}{y_c}, \frac{\Delta E}{Eo}, \theta, N_s, F_r, \frac{R}{y_c}\right) \quad (3)$$

Since (B, R) are kept constants throughout the experimental program, so equation (3) becomes:

$$\frac{\Delta E}{E_0} = Ø_4 \left(\frac{y_0}{y_c}, \frac{y_1}{y_c}, \frac{h}{y_c}, \frac{l}{y_c}, \frac{\Delta E}{Eo}, N_s, \theta, F_r\right) \quad (4)$$

$\Delta E/E_0$:Relative energy loss;
y_0/y_c:Relative depth of the water in upstream;
y_1/y_c : Relative depth of the water just downstream
h/y_c : Relative height of the spillway step; and
l/y_c : Relative length of the spillway step.

The present study aims to investigate the effect of the following parameters on the energy dissipation over-stepped spillways:

1) Effect of step length

$$\frac{\Delta E}{E_0}=\O_5\left(\frac{\square_0}{\square_c},\frac{\square_1}{\square_c},\frac{l}{y_c},\theta,F_r\right) \quad (5)$$

2) Effect of number of steps

$$\frac{\Delta E}{E_0}=\O_6\left(\frac{y_0}{y_c},\frac{y_1}{y_c},\frac{h}{y_c},\frac{l}{y_c},N_s,F_r\right) \quad (6)$$

3) Effect of length of reverse slope

$$\frac{\Delta E}{E_0}=\O_7\left(\frac{y_0}{y_c},\frac{y_1}{y_c},\frac{l_r}{y_c},F_r\right) \quad (7)$$

4) Effect of radius of end sills

$$\frac{\Delta E}{E_0}=\O_8\left(\frac{y_0}{y_c},\frac{y_1}{y_c},\frac{r_s}{y_c},F_r\right) \quad (8)$$

In the final stage the best previous results with the stagger step formation on the energy dissipation and flow aeration are compared...

$$\%DO=\O_9\left(\frac{y_0}{y_c},\frac{y_1}{y_c},\frac{r_s}{y_c},\frac{l_r}{y_c},F_r\right) \quad (9)$$

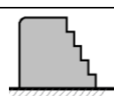
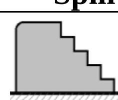
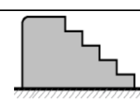
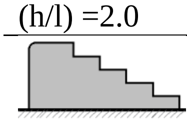
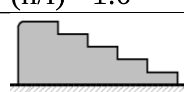
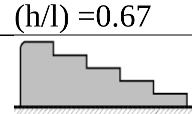
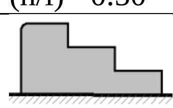
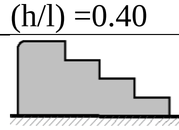
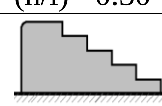
4 EXPERIMENTAL PROGRAM

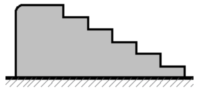
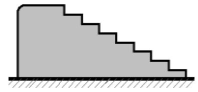
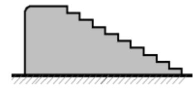
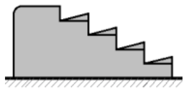
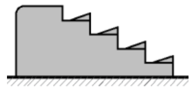
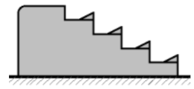
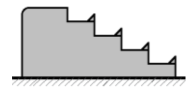
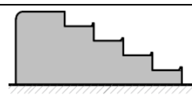
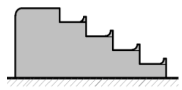
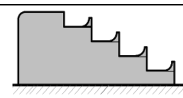
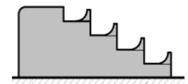
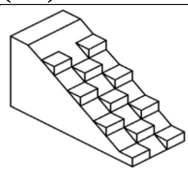
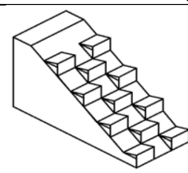
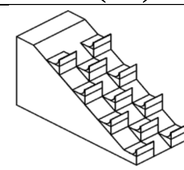
Using the above reviewed results of the most popular researches, studies, compassions, and analyses, the present study, concerning that topic, will be divided into five stages as follows:

- Stage No. (1): determining the best effective relative ratio between the step height and the step length (h/l).
- Stage No. (2): determining the best effective number of steps(N_s), and suitable relative ratio between the step height and the total spillway height (h/H).
- Stage No. (3): determining the best effective relative length of reverse slope to the total length of the step (l_r/l).
- Stage No. (4): determining the best effective relative ratio of end sill radius to the step height (r_s/h).
- Stage No. (5): studying the effect of staggered step formations.

Used experimental models and different stages are shown in the following table (4).
Experiments will be carried out in a horizontal channel of rectangular cross-section of 20 m length, 0.30 m width, and 0.50 m depth in the irrigation and hydraulic laboratory of Civil Department, Faculty of Engineering, Assuit University, Egypt.

Table 4. Experimental models and stages of testing.

Stage No.	Spillway Geometry		
Relative ratio of step height to step length (h/l)	 (h/l) =2.0	 (h/l) =1.0	 (h/l) =0.67
	 (h/l) =0.50	 (h/l) =0.40	 (h/l) =0.30
Relative ratio of step height to total	 (h/H) =0.33	 (h/H) =0.25	 (h/H) =0.20

spillway height (h/H)	 (h/H) =0.17	 (h/H) =0.13	 (h/H) =0.10	
Relative length of reverse slope (lr/l)	 (lr/l) =1.0	 (lr/l) =0.75	 (lr/l) =0.50	 (lr/l) =0.25
Relative radius of end sill (r/h)	 (r/h) =0.20	 (r/h) =0.40	 (r/h) =0.60	 (r/h) =0.80
Staggered Formation				

5 DISCUSSION

From the previous studies, it is observed that all experimental and numerical results concluded that; the energy dissipation increases with decreasing the angle of the spillway back surface (Ɵ), but there is a disagreement between the results about the effect of number of steps (N_s) on the energy dissipation for stepped spillways. Results given by Khalaf (2014) ; Al-Husseini (2015) ; Irzooki, (2016); Tabari and Tavakoli, (2016) indicated that; the energy dissipation increases with decreasing number of steps, On the contrary to those presented by Rad and Teimouri (2010) and Jahad et al. (2017) which concluded that, with increasing the number of steps (N_s) the energy dissipation increased.

Owing to such contradictions in results, the present study will be conducted to clarify which of these results are correct and at the same time, to introduce a new geometrical spillway back body surface , which gives more energy dissipation. The increase of energy dissipation will increase the flow dissolved oxygen content and consequently improves the irrigation water quality. The study also aims to estimate accurately the effective number of steps (N_s), and the effective relative ratio between the step height (h) to the total height of the stepped spillway (H).

6 CONCLUSIONS

From the present comparative review carried out for the most technical models for improving the energy dissipation and flow aeration over the stepped spillways ,the following conclusions can be drawn down:

- Many researchers studied the effect of steps on the back surface of spillways; however, there is a disagreement with their results about the effect of increasing the step's number on the energy dissipation.
- There is a defect in estimating the effective number of steps (N_s), and the best relative ratio between the used step height to the total height of spillways (h/H).
- The reverse inclined slope of the step was studied widely, but, none of them (as the best of our knowledge) studied the best effective relative ratio of length of the reverse slope to the total length of the step(l_r/l).

- The above-mentioned main conclusions are the main technical approach used to introduce a new geometrical treatment for the spillways of more efficient energy dissipation and enhancing the water quality by increasing its dissolved oxygen content at the same time.

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