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Kinetic Energy Dissipation on Labyrinth Configuration Stepped Spillway

Jaafar S. Maatooq
Building and Construction Dept., University of Technology, Baghdad, Iraq
E-mail: jaafarwes@yahoo.com , jaafarmaatooq@gmail.com, 40071@uotechnology.edu.iq

Abstract

In present work a labyrinth (zigzag), in shape has been used to configure the steps of stepped spillway by using the physical model. This configuration does not introduce previously by investigators or in construction techniques of dams or cascades. It would be expected to improve the flow over chute. A magnifying the width path of each step to become, L_T, instead of, W, will induce the interlocking between the mainstream and that spread laterally due to labyrinth path. This phenomenon leads to reduce the jet velocities near the surfaces, thus minimizing the ability of cavitation and with increasing a circulation regions the ability of air entrainment be maximized. The results were encouraging, (e.g., the reverse performance has recorded for spillway slope). From the evaluation of outcome, the average recorded of percentage profits of kinetic energy dissipation with a labyrinth shape compared with the results of traditional shape were ranged between (13- 44%). Different predictive formulas have been proposed based on iteration analysis, can be recommended for evaluation and design.

Keywords: Stepped spillway, Skimming flow, Overflow energy dissipation, Labyrinth weir, Air entrainment, Circulation regions.

تبديد الطاقة الحركية فوق المطفح المدرج بتشكيل متاهة

الخلاصة

في هذه الدراسة تم تبني شكل المتاهة (Labyrinth) لتشكيل مدرجات المطفح المدرج باستخدام نموذج فيزيائي . هذا التشكيل لم يتم اعتماده سابقا من قبل الباحثين ولا حتى ضمن التطبيقات في أنشاء السدود والمنحدرات . يمكن توقع تطوير طبيعة الجريان فوق السطوح المنحدرة باتجاه الزيادة في تبديد الطاقة الحركية. أن تضخيم عرض مسار الجريان لكل تدريجة ليصبح L_T بدلا من W سوف يسمح بتداخل الجريان ما بين المسار الرئيسي وذلك الذي يتم توزيعه جانبيا بسبب تشكيل المتاهة . تلك الظاهرة تؤدي الى التقليل من سرع البثق قرب سطوح التدريجات وبالتالي التقليل من قابلية النخر (Cavitation) ومع الزيادة بمناطق الدوامات سيؤدي ذلك الى الزيادة في تداخل الهواء . ان النتائج كانت مشجعة أذ تم تأشير تأثير عكسي خصوصا من ناحية ميل سطح المطفح ومن خلال تحليل النتائج فأن معدل نسب الربح في زيادة تبديد الطاقة الحركية باستخدام هذا التشكيل عن تلك المتحققة فوق المطفح المدرج التقليدي كانت تتراوح ما بين (13- 44%). تم اقتراح مجموعة معادلات حسابية بعد اعتماد طريقة المحاولات يمكن استخدامها لأغراض التحليل والتصميم.

الكلمات الدالة : المطفح المدرج، تبديد الطاقة، تداخل الهواء، مناطق التدوير..

Introduction

Since the development of Roller Compacted Concrete (RCC) techniques for the construction of concrete dams, the behavior of aerated flow on stepped spillway was investigated in extensive experimental and numerical models those adopted by researchers over the world. All researches were conducted on conventional chute steps with some trials to modify the geometry of steps such as in shape or roughness. The key feature associated with steps and its modification is to magnify the amount of kinetic energy dissipation over it. Reduce the requirements of the appurtenances and size of the energy dissipater at toe accordingly. The first aim of any related research is how to elongate the air entrainment path along chute and how to increase aeration by the enhance and maximize these two requirements it will be expected to increase the performance of spillway for more dissipation of kinetic energy. In literature, many trials for steps modification include; inclined upward steps, end sills for each step, adding baffles row or blocks, turbulent manipulators, and macro-roughness systems[1-5]. All modifications which adopted in literature may effectively enhance flow resistance, and produce more energy dissipation but their attractiveness in counterbalanced by increasing a structural load to the steps and, as a result, on a foundation. However, the additional benefits of increases the kinetic energy dissipation may not cover the increasing in cost due to the need for particular construction methods include a skill labors as well as lengthen the construction period, besides needs more quantity and quality of materials. Accordingly, and from the fact that the development of such structures is still dynamic and need more experimental trials for an integrated approach. Such trials consist adopting more practical features having advantages for; increasing the energy dissipation, reducing damage due to cavitation, and fewer construction costs as possible. In present work a labyrinth (zigzag) shape used to configure the steps of spillway by using a physical model. It will be expected to improve the flow over chute, where with a magnifying the width path of each step, the interlocking surface areas between the mainstream and that spread laterally due to zigzag have been increases lead to increase the circulation regions then the air entrainment has been increasing thus reduces the cavitation action. However, structurally, this configuration indeed reduces the construction cost and time as well as the loading at a foundation as a result, by reducing the volume of materials need for each step compared to traditional. The aim of present study is to evaluate the residual energy at toe by observing the energy losses along spillway. The physical models of stepped spillway are used to configure labyrinth ratios via experimental program conducted in a laboratory flume.

Background

The skimming flow regime adopted in present work, where in this flow the external edges of steps configure a pseudo-bottom. Beneath this bottom, recirculation vortices developed and formed by almost triangular cells where the water remains in circulation except that exchanged with the upper flow due to high turbulence. The friction over this surface provides enough energy for trapped vortices to continue rotating. At skimming flow, the entrance of air into flow will begin, and that typically occurs when inertia force overcome a gravity and surface tension forces, is precisely happen in this regime. However, skimming flow occurs with moderate to high discharges that are usually going on in practice. The effective parameter that used to recognize a skimming flow from jet (nappe) flow is “critical depth of flow over a crest of spillway related to step height” (y_c/h). Rajaratnam, 1990[6], stated that “when ($y_c/h=0.8$), the onset of skimming flow will form”. For chute angle $\theta \geq 30^o$, the main flow almost skim above a pseudo-bottom and does not impact near the step edge, at the same time, the recirculating fluid formed between tread of step and rise of the previous one. In this case, the effect of the main flow on the energy dissipation may be small and the energy dissipated mainly by the action of circulating fluid [2,6,7,8]. The amount of kinetic energy dissipation on stepped spillway or cascades can express as a difference between the energy at the crest and the residual energy at the toe, ($E=Eo-E1$). The energy at a spillway crest does not influence the flow regime, but with the height, where the potential energy component increases with increase the height of crest and in stepped spillway the crest height is an accumulation of steps rises. After flow passing the crest towards the toe, the dissipation of kinetic energy was accomplished along chute, and a more dissipation occurs as a results with modified steps configurations[3], thus in skimming flow regime, the steps act as large roughness elements. In literature, the most influences parameters on energy dissipation are; the step rise, (h) and the tread of step, (s). The dimensionless form of these two parameters is “h/s”, which representing the inclination angle of a spillway, (θ). The other parameter that directly affects the dissipation is the number of steps.This parameter has a direct influence on potential energy, where its total number represent the height of crest “H_{dam}” above the toe level. The step roughness height perpendicular to the pseudo-bottom (skin roughness) “Ks” it also has a tangible effect. Finally the critical flow depth over the crest “y_c”, where it reflect the influence of discharge. In skimming flow rotation in a lower area beneath the pseudo-bottom formed by almost triangular cells which have a significant effect on energy dissipation. In conventional stepped spillway, this rotation phenomenon is at the same influencing action in the lateral direction (width of spillway). The major aim of a present study is to modify the geometric configuration of step. This modification is to create suitable hydraulic phenomena to change an interference action along the lateral direction by increasing the interlocking between a streamwise recirculation and a secondary circulation which is formed locally in between a labyrinth path to provide more vortices and hence increasing air-water mesh. As a result, the more kinetic energy has been dissipated accordingly, see Figure (1).

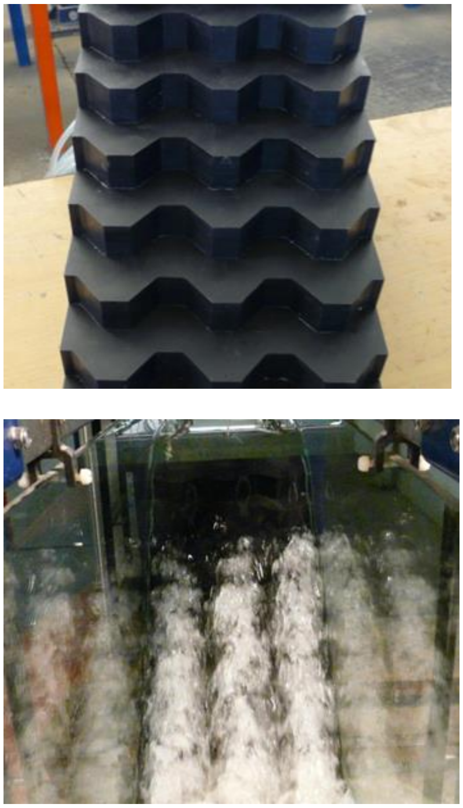

Fig.1. Effect of zigzag lateral direction of steps (labyrinth shape) on hydraulic performance (After Taha Y. Ojaimi,2009)[9]

Experimental Setup and Procedure

The data that adopted by this study is part of the laboratory measurements conducted by M.Sc. student[9]. The experiments conducted via flume available in the department of mathematical and physical models, Center for the Studies and Engineering Design “CSED”, Water Ministry of Iraq. The flume has a working section 0.3m in wide, 0.45m in depth and 12.5m in length. Water circulation in the flume by a centrifugal pump from sump tanks and regulated manually by butterfly valve to measure the desired flow rate by electromagnetic flowmeter displayed on a digital readout in (l/s) located on the front of the electrical console.

The water depth measurements were conducted using a point gauge with accuracy ±0.1mm. In present work, a three physical models of the spillway at angles, ($\theta=35^o$, 45^o, and 55^o) were adopted for a crest at height 32cm. With each, four stepped configurations used; one configured a traditional stepped spillway. Other models configured a labyrinth shape at (Lr=1.1, 1.2, and 1.3), where Lr is a ratio of a lateral length of step, L_T, to the width of the flume, W (represent a lateral length of traditional step), see Figure (2). A whole twelve models categorized into three groups related to spillway angles. In all models the step rise, h was kept at 4cm, and the three step tread, (s =5.7cm, 4cm, and 2.8cm) have selected in such a manner that the arctan of h/s resulting angle spillway ($\theta=35^{o}$, 45^{o}, and 55^{o}) respectively. According to the available hydraulic conditions and limitations, a compromise has been made for chosen the dimensions of a model, a number of steps, and zigzag number for each step. Six flow rates between 6 l/s and 16 l/s were used to simulate the skimming flow with y_c/h ranged between 0.86 and 1.655. As previously mentioned, the aim is to calculate the residual energy at toe of spillway, E1 for all twelve models then compare this residual with the available energy at crest of spillway, Eo as referred in Figure (3), where;

$$Eo=H_{dam}+E_{min} \qquad \text{………………………………(1)}$$

Equation (1) can write in another form;

$$Eo = y_o + \frac{q^2}{2gy_o{}^2} \qquad \text{…………………………..(2)}$$

The form of Equatio (1) needs accurate measures of critical depth over a crest of the spillway that occurs just when the crest is uncontrolled and represented a standard broad crested weir. The flow energy at toe of spillway is a specific energy concept;

$$E1 = y1 + \alpha1\frac{q^2}{2gy1^2} \qquad \text{……………………..(3)}$$

The depth of flow at the toe of a spillway, y1 is considered the initial depth of hydraulic jump, as illustrated in Figure (3). This depth cannot measure directly. Also, the kinetic energy correction factor α1 is taken equal 1.1 and from the measurement of the sequent depth, y2 the initial depth was calculated using the following formula as recommended by[10] and used in the works conducted by [1,11];

$$y1 = \frac{y2}{2}\left(\sqrt{1 + 8\left(\frac{q^2}{gy2^3}\right)} - 1\right) \qquad \text{…………(4)}$$

The resulted y1 then substituted in Equation (3) to calculate the residual energy at a spillway toe, E1.

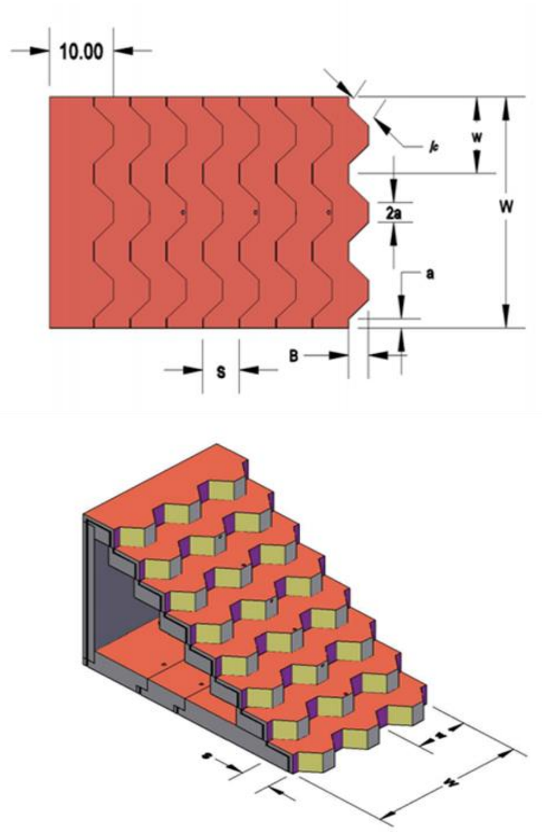

Fig. 2. Plan and perspective sketch of Labyrinth configuration stepped physical spillway model (After Taha Y. Ojaimi,2009)[9]

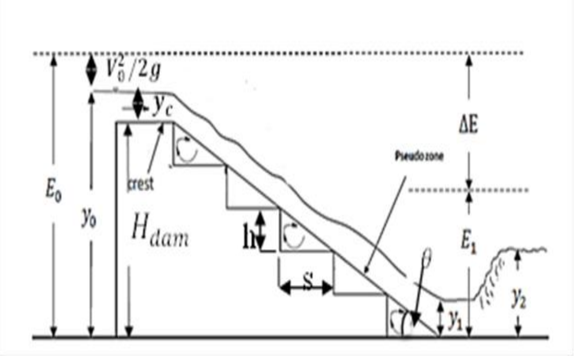

Fig. 3. Typical scheme of a stepped spillway

Influencing Parameters

The difference between Equations (1) or (2) and Equation (3), is the magnitude of the kinetic energy dissipated along chute of the spillway. This difference denoted, E, and as E increases that refer to the high performance of a selected specified configuration of the chute.

This amount of dissipation when normalized with initial energy, Eo, the energy dissipation efficiency was found out by relative dimensionless term E/Eo. The significant quantity of this term has found been a function of how many steps in a spillway and y_c/h as concluded by many researchers[12-16], and many others. Based on roughness manner of steps[17-19], other investigators show that roughness factor of a stepped chute, differs from smooth one by introducing the skin roughness factor, ($Ks=h\cos\theta$). This factor has the main effect on dissipation of energy in case of skimming flow regime. Accordingly in a present study, the same influencing parameters as adopted by previous researchers have been taken as a function of kinetic energy dissipation. However, a new conceptual parameter was introduced that related to the labyrinth shape configuration named as labyrinth ratio, denoted as, ($Lr=L_T/W$). As can see from Figure (2). The magnification lateral dimension of each step can be calculated by;

$L_T=n(4a+2lc)$ ……………………………….(5)

Where; n = cycles number (n=3 in this study), a, is a half crest length of labyrinth cycle, and lc, is a side dimension of labyrinth cycle. Concerning to the labyrinth shape stepped spillway this study has focused on investigating the influence and trend of Lr beside the governing traditional parameters, Ks and y_c, on the amount of energy dissipation over the steps and, as a result, on the residual energy at the spillway toe.

Analysis of Results

Initially, the flow rate, the labyrinth ratio and the angle of spillway have been evaluated to show their effects on kinetic energy dissipation. Figure (4) illustrates that, generally, the residual energy still high as the discharge increase for all spillway angles and steps configurations. On the other word, a higher dissipation of kinetic energy resulted with low rates of discharge. It is agreement with conclusions have been presented by other researchers[2,20,21,22]. To show the effect of labyrinth ratio, Figure (5) illustrates that this ratio has the appreciable influence on kinetic energy dissipation, where the dissipation increases with increasing this ratio for all spillway angles. However, a more efficient hydraulic performance was with ($\theta=35^o$), with this angle a functional relationship of energy dissipation with labyrinth ratio Lr has a linear trend. Based on a linearity of this relation it could be expected more increases the dissipation of kinetic energy as a labyrinth ratio increases beyond 1.3, while, for other angles the trend of benefit was nonlinear, refer to expect a constant or ineffective influence of Lr beyond 1.3. However, a reverse behavior of spillway angles recorded for labyrinth shape as compared with conventional stepped spillway, as seems in Figure (6), where the trend of energy dissipation decreases with increasing the spillway angle, while reverse performance occurs with labyrinth configurations. That could attribute to that for traditional stepped spillway the significant decreases in efficiency with increasing the angle of spillway may be due to decreases the influence of skin roughness, where Ks, decreases as θ, increases. That also stated in bibliographic analysis such as (Hazzab and Chafi)[20], and others, that; the energy dissipation corresponding to skimming flow regime has strongly depended on skin roughness (friction factor). With a labyrinth shape models, the interlocking surface areas between the mainstream and trapping cavity, create more recirculating vortices which have a great influence than Ks. Moreover, this action increases as θ increases. That attributed to, for a shorter steps treads, a reverse action of vortices along lc, see Figures (1) and (2), between successive steps will increasing the dissipation. On the other hand, as a labyrinth ratio increases this influence decays, it is due to the emergence of the impact of Lr parameter at the expense of the spillway angle, Figure (5) is illustrates this action. The percentage values of profit in dissipation with adoption a labyrinth shape configurations illustrated in Table (1).

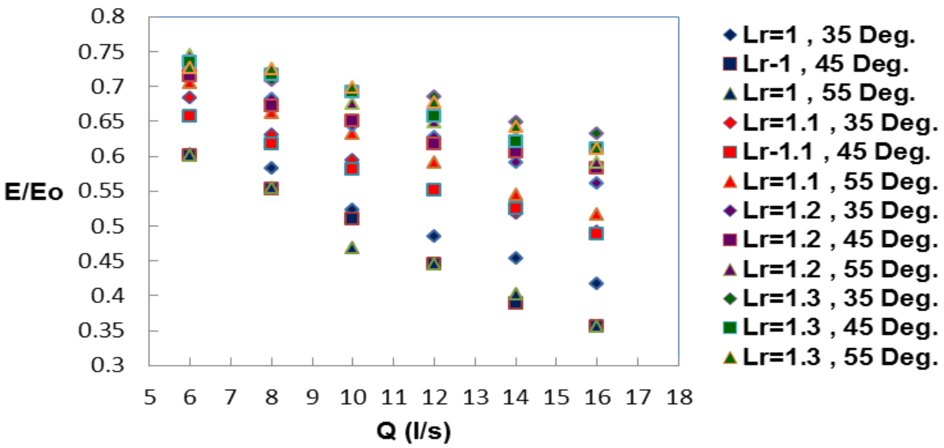

Fig. 4. Variation the kinetic energy dissipation with discharge based on different steps configurations

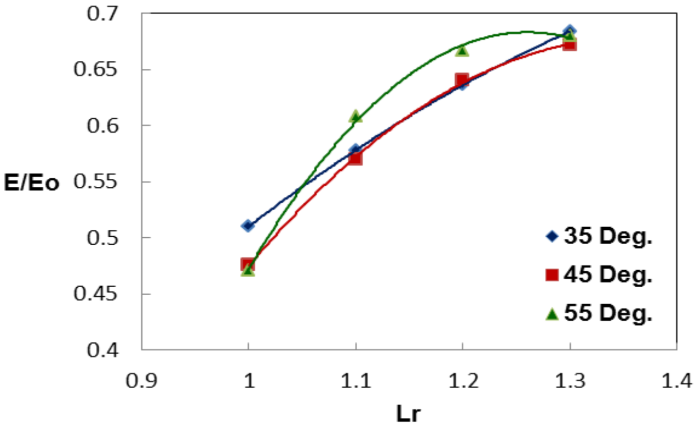

Fig. 5 Variation the Kinetic energy dissipation with Labyrinth ratio for spillway slopes

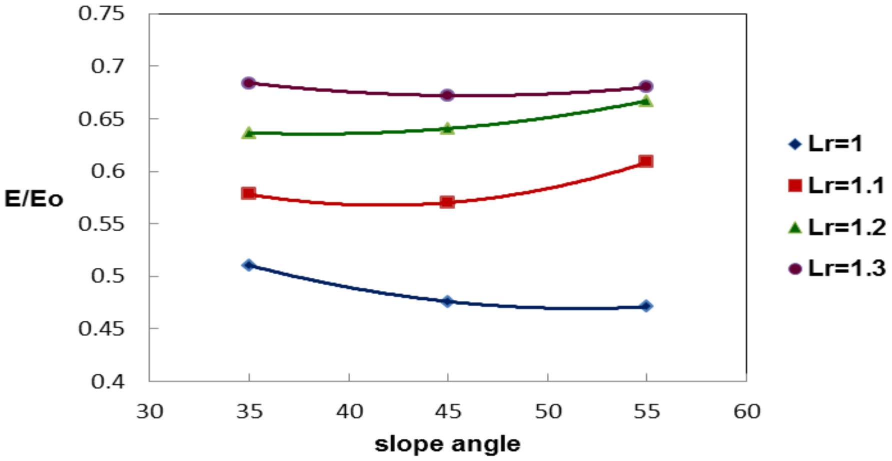

Fig. 6. Variation the kinetic energy with slope of spillway for different Labyrinth ratios

Table. 1. The percent benefits in Kinetic energy dissipation with Labyrinth configuration

θ	% Increase in (E/Eo)		
	Lr=1.1	Lr=1.2	Lr=1.3
35^o	13	25	34
45^o	20	34.5	41
55^o	29	41.5	44

Energy Dissipation Parameters

Several formulas have been devised previously based on results concerning the energy dissipation at skimming flow as a function of (H_{dam}/y_c). Chanson[19], shows that the residual energy was a function of friction factor, f and, (H_{dam}/y_c). This factor is a function of skin roughness, Ks. The Chanson's relationship was done by earlier works[18,23,24]. Boes and Minor[17], was also introduced the same form of a relationship with some modification. Hazzab[20], concluded from his analysis of experimental results of 32^o, stepped spillway, that (H_{dam}/y_c), have a direct effect on residual energy computation. Ohtsu et al.[8], Stefano et al.[25], and Stefan and Chanson[26], are also reported the same relations. However, some investigators showed that the number of steps has a strong correlation with energy dissipation. This parameter presented as a dimensionless term (y_c/Nh), where N referred to steps number, Sandip[27], Maatooq[16], and Dermawan et al.[28], has been worked on this relationship. In present work, the initial trials conducted to investigate more reliable parameters on the amount of energy dissipation over spillway; the trials iterations rested to; that the normalized energy dissipation (E/Eo), was depends strongly on; skin roughness Ks, flow discharge that represented by y_c, and labyrinth ratio Lr. These three affecting parameters are linked to give one nondimensional independent parameter to correlate with relative energy dissipation as;

$$\frac{E}{Eo} = f\left(\frac{Ks\ Lr}{y_c}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

Statistical error indices should test the reliability of Equation (6). The most common statistical indices are; the Mean Absolute Error (MAE), the Root Mean Square Error (RMSE), the Mean Bias Error (MBE), Nash-Sutcliffe Efficiency Coefficient (NSEC), Percent Bias (PBIAS), and the determination coefficient (R^2). These indices are listed in brief details herein.

Model Evaluation Statistics

The indices represent; MAE, RMSE, and MBE, are valuable. These indicators present error in the units (or square units) of the constituent of interest which aid in analysis of results[29], The mathematical forms of these statistical indicators as presented by Moriasi, et al., cited by Javaid et al.[29] are;

$$MAE = \left[\frac{1}{n}\sum_{i=1}^{n}\left|\left(\frac{E}{Eo}\right)_o - \left(\frac{E}{Eo}\right)_s\right|\right] \quad \ldots\ldots\ldots(7)$$

$$RMSE = \left[\frac{1}{n}\sum_{i=1}^{n}\left[\left(\frac{E}{Eo}\right)_o - \left(\frac{E}{Eo}\right)_s\right]^2\right]^{0.5} \quad \ldots(8)$$

$$MBE = \frac{1}{n}\sum_{i=1}^{n}\left[\left(\frac{E}{Eo}\right)_o - \left(\frac{E}{Eo}\right)_s\right] \quad \ldots\ldots\ldots\ldots(9)$$

Where (E/Eo)o and (E/Eo)s, are the observed and simulated relative dissipation energy respectively, and n, is a range of data. Zero values of the above indicators refer to a perfect fit. NSEC is a normalized statistics that determines the relative magnitude of residual variance compared with the measured data variance. It is dimensionless indicator recommended by the ASCE 1993, cited by Javaid [29], this index when located between 0-1, that viewed as an acceptable performance level, whereas when its value is less than zero that refer to an unacceptable performance, the form of this index is;

$$NSEC = 1 - \left[\frac{\sum_{i=1}^{n}\left[\left(\frac{E}{Eo}\right)_o - \left(\frac{E}{Eo}\right)_s\right]^2}{\sum_{i=1}^{n}\left[\left(\frac{E}{Eo}\right)_o - \left(\frac{E}{Eo}\right)_{o,av.}\right]^2}\right] \quad \ldots.(10)$$

Where $\left(\frac{E}{Eo}\right)_{o,av.}$, is the mean of the observed data. The percent bias, P-BIAS, also recommended by ASCE 1993, which measures the general tendency of simulated data to be larger or smaller than the observed values. This indicator can indicate clearly the poor model performance. Since the optimal value of PBIAS is zero, the lower (near zero) values indicate better model simulation, this index calculated by;

$$PBIS = \left[100x\frac{\Sigma_{i=1}^{n}\left(\frac{E}{Eo}\right)_{o}-\left(\frac{E}{Eo}\right)_{s}}{\Sigma\left(\frac{E}{Eo}\right)_{o}}\right] \quad \text{.........(11)}$$

Governing Formula

As previously explained, more dominant parameters having influence on the amount of energy dissipation are:-

- skin roughness; Ks (which is a function of step rise h and spillway angle, θ),
- critical depth over the crest y_c (which is a function of flow rate), and
- Labyrinth ratio Lr (which is a function of magnification lateral distance of step L_T to the width of spillway W).

The statistical software (Minitab-16) was used to correlate Equation (6), and the statistical error indices have examined the resulted formulas. After numerous and different iterations of several statistical correlation equations, the forms of the exponential model were restated as listed in Table (2) with the values of validation indices. The analysis was made to correlate a formula of Equation (6) for each of the following practical cases:

Case1; using different labyrinth ratio, Lr in design for a specified angle of the spillway, θ.

Case2; using different labyrinth ratio, Lr for any angle of the spillway, θ (general model).

Case3; using a specified labyrinth ratio, Lr for any spillway angle, θ.

The more reliable formula according to case1, was for ($\theta=55^o$), where the test indicators are resulting a higher R^2, less MAE, RMSE, and P-BIS. However, the value of NSEC when approaching to one that refers to high acceptable performance level. The percent bias value of the model also refers to that the common tendency of simulated data tends towards zero, that is means a better model simulation. Consequently, the predictive formula recommended for estimate the amount of kinetic energy dissipation for practical application based on case one is;

$$\frac{E}{Eo} = 0.742 - 2.515\ e^{\left(-6.405\frac{Ks\ Lr}{yc}\right)} \quad \text{......(12)}$$

This formula has been used for spillway angle 55^o and with any labyrinth design ratio, Lr. Figure (7) also illustrates that with ($\theta=55^o$), a better performance to dissipate more kinetic energy for all Lr ratios than other spillway angles. This conclusion attributed to a nearly perfect distribution of experimental data near the trend line.

The correlation of general formula (case2) indicates clearly the acceptable but not reliable model performance. However, the main bias error, MBE and the percent of bias P-BIAS, shows well perfect model. The nearly best fit of these indices refers to the negligible effect of the main error, and Figure (8) illustrates that the variance between observed and simulated tends to decrease when (E/Eo>0.625). This tendency can occur with both (Lr=1.2 and 1.3) for all spillway angles as seems in Figure (4). Moreover, least differences in results were recorded between (L_r=1.2 and 1.3) for ($\theta=55^o$). This finding is also well illustrated in Figures (6) and (9). Accordingly, the proposed general formula was taken the following form with precaution in application;

$$\frac{E}{Eo} = 0.81 - 0.477\ e^{\left(-1.528\frac{Ks\ Lr}{yc}\right)} \quad \text{........(13)}$$

The precaution restricted when the expected relative energy dissipation to be less than 0.625, and for (Lr=1.1).

In a focus of case3, the most reliable formula was for a labyrinth ratio (Lr=1.3) for any angle of a spillway. This conclusion is due to that the indicators for this ratio are better compared to the results for other ratios of case3. The observed data points tend towards the best-fit line of (Lr=1.3) more than as for other labyrinth ratios that clearly seen in Figure (10). Consequently, Figure (11c) shows a well fit between observed and predicted relative energy dissipation for (Lr=1.3). The reliable predictive formula for case3 as recommended to used with all spillway angels and (Lr=1.3) is;

$$\frac{E}{Eo} = 0.78 - 0.38\, e^{\left(-1.848\frac{Ks\ Lr}{y_c}\right)} \quad \text{……...(14)}$$

It should be recommended here to use Equation (12), the design of spillway is at 55° and labyrinth ratio needs to be equal 1.3.

Table. 2. The Proposed Models Formulas with Statistical Test Indices

<table>
<tr><td colspan="6">For all Labyrinth ratios with θ=35°</td></tr>
<tr><td>MAE</td><td>RMSE</td><td>MBE</td><td>NSEC</td><td>PBIS</td><td>R^2</td></tr>
<tr><td>0.02236</td><td>0.02664</td><td>0.000113</td><td>0.84653</td><td>0.01785</td><td>0.8</td></tr>
<tr><td colspan="6">$\frac{E}{Eo} = 0.725 - 2.45\, e^{\left(-4.415\frac{Ks\ Lr}{y_c}\right)}$</td></tr>
<tr><td colspan="6">For all Labyrinth ratios with θ=45°</td></tr>
<tr><td>0.0238</td><td>0.02685</td><td>0.000048</td><td>0.83042</td><td>0.00764</td><td>0.831</td></tr>
<tr><td colspan="6">$\frac{E}{Eo} = 0.744 - 1.315\, e^{\left(-3.704\frac{Ks\ Lr}{y_c}\right)}$</td></tr>
<tr><td colspan="6">For all Labyrinth ratios with θ=55°</td></tr>
<tr><td>0.01337</td><td>0.01543</td><td>0.000743</td><td>0.93843</td><td>0.006592</td><td>0.937</td></tr>
<tr><td colspan="6">$\frac{E}{Eo} = 0.742 - 2.515\, e^{\left(-6.405\frac{Ks\ Lr}{y_c}\right)}$</td></tr>
<tr><td colspan="6">For all Labyrinth ratios with all slope angles</td></tr>
<tr><td>0.03785</td><td>0.04758</td><td>0.000014</td><td>0.48013</td><td>0.002201</td><td>0.501</td></tr>
<tr><td colspan="6">$\frac{E}{Eo} = 0.81 - 0.477\, e^{\left(-1.528\frac{Ks\ Lr}{y_c}\right)}$</td></tr>
<tr><td colspan="6">For Lr=1.1 with all slope angles</td></tr>
<tr><td>0.03683</td><td>0.04673</td><td>0.000071</td><td>0.47742</td><td>0.01214</td><td>0.553</td></tr>
<tr><td colspan="6">$\frac{E}{Eo} = 1.355 - 0.97\, e^{\left(-0.368\frac{Ks\ Lr}{y_c}\right)}$</td></tr>
<tr><td colspan="6">For Lr=1.2 with all slope angles</td></tr>
<tr><td>0.03069</td><td>0.05142</td><td>0.000097</td><td>0.44055</td><td>0.01502</td><td>0.543</td></tr>
<tr><td colspan="6">$\frac{E}{Eo} = 1.11 - 0.627\, e^{\left(-0.446\frac{Ks\ Lr}{y_c}\right)}$</td></tr>
<tr><td colspan="6">For Lr=1.3 with all slope angles</td></tr>
<tr><td>0.020291</td><td>0.024351</td><td>0.000048</td><td>0.66033</td><td>0.00708</td><td>0.668</td></tr>
<tr><td colspan="6">$\frac{E}{Eo} = 0.78 - 0.38\, e^{\left(-1.848\frac{Ks\ Lr}{y_c}\right)}$</td></tr>
</table>

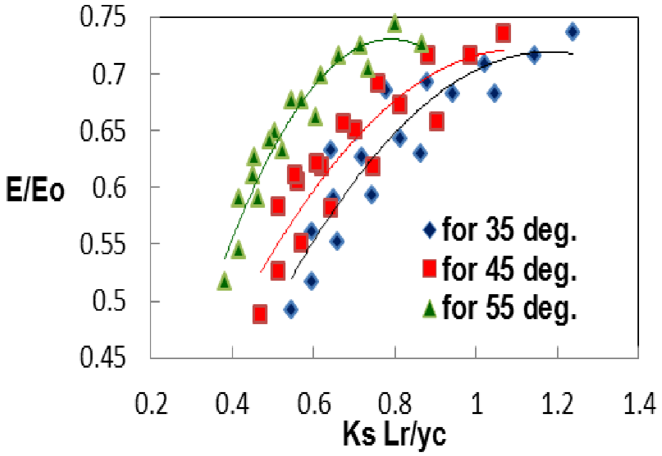

Fig. 7. Influence of independent dimensionless parameter on dissipation of kinetic energy for different spillway slope angles

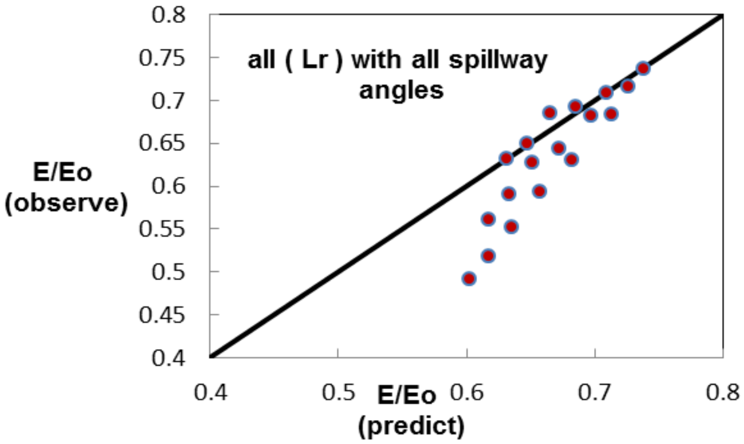

Fig. 8. Comparison the measured with simulated data by Eq.13

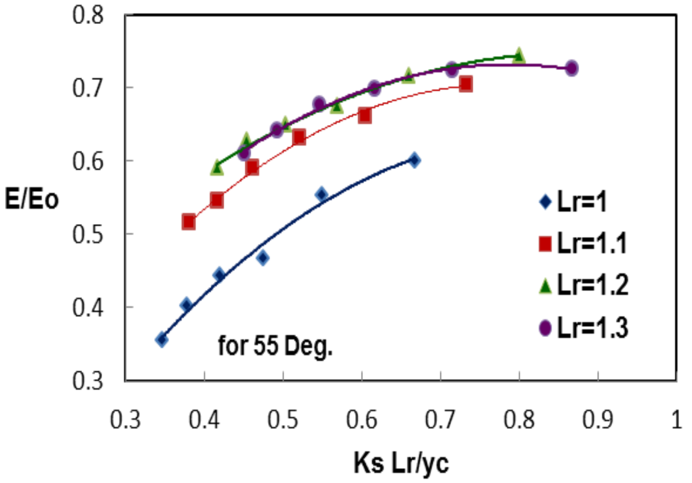

Fig. 9. Influence of independent dimensionless parameter on dissipation of kinetic energy for various Labyrinth ratios with θ=55°

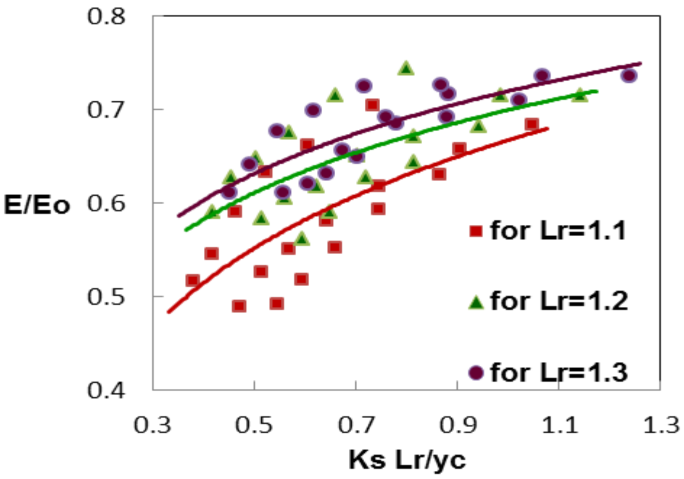

Fig. 10. Influence of independent dimensionless parameter on dissipation of kinetic energy for various Labyrinth ratios with all spillway angles

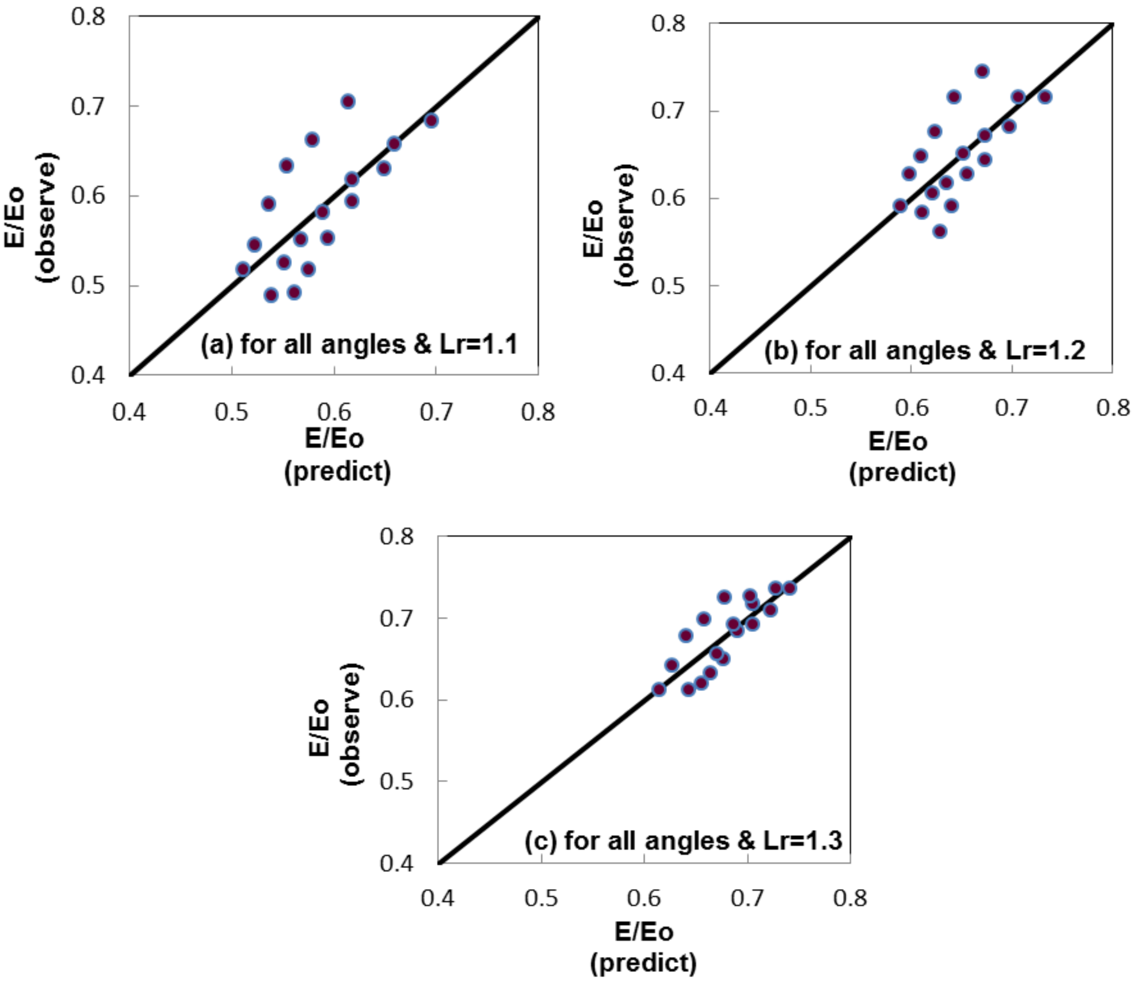

Fig. 11. Comparison the measured with simulated data for case3 practical situation

Conclusion

The aim of the present study to find the effect of a new configuration of stepped spillway named as “labyrinth shape” on the amount and trend of kinetic energy dissipation over chute. The results were encouraging, firstly the reverse performance has been recorded for spillway slope, where in traditional stepped spillway the dissipation of energy decreases with increasing the slope (i.e., θ), whereas with labyrinth configuration an increase in the slope of spillway tends beside the advantageous of dissipation performance. From the evaluation of results, the average recorded of percentage profits in the dissipation of kinetic energy for employment the labyrinth shape instead of traditional shape in stepped spillway are ranged between13% to 44%. The different predictive formula has been extracted based on iteration analysis, can be recommended to use for evaluation and design within the case under the study.

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