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# Performance of Screen Wall Openings Shape on Energy Dissipation

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**Abstract**— Hydraulic jump is important phenomena for dissipating energy in open channels. Screen walls are proposed to be used as an energy disperser in small hydraulic structures. An experimental study in a laboratory flume is carried out to study the effect of holes shape in the screen wall on the efficiency of the energy dissipation. Three holes of different shapes were used in screen walls, circular, square and hexagonal of two different dimensions for each model, with a fixed porosity of 40%. The screen walls were anchored at a distance of 80 and 120 times the gate opening for each model. The basic principles of conservation and statistical analysis are employed to correlate between hydraulic and dimensionless parameters of relative distance and shape openings with percentage of energy dissipated. Different relationship models with acceptable significance are suggested. It was found that the major parameter effecting significantly on energy dissipated is FrG while the other dimensionless parameters (X/D, $L/y_G$, $h/y_G$, $d1/y_G$) have less significance. The energy dissipated by all shapes opening is more than classical hydraulic jump and the performance decreases with increase of Froude number. Within the limitations of the present experimental work a simple general linear equation for predicting the percentage of energy dissipation is proposed different discharge equations were predicted with $R^2$ of 0.932.

**Index Terms**— energy dissipation, dimensionless parameters, Froude number, hydraulic jump, opening shape, porosity, screen wall.

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## 1 INTRODUCTION

The generated kinetic energy from high velocity downstream hydraulic structures is necessary to be dissipated to protect the structure itself and prevent erosion and the dissipation of the kinetic energy is essential for bringing flow into normal condition in a short distance. Wide ranges of energy dispersion techniques are introduced such as stilling basins, free jets, impact, and roller buckets [1]. Although, a large number of designs of energy dispersion that meet the practical needs but the investigators proposed unconventional methods to dissipate the energy such as screen walls. The study of the flow through screens is a practical issue in hydraulic structures. Experimental study of the head loss for different screen opening and their position in open channel had been carried early, the coefficient of head loss was predicted [2]. Numerical solution for the mass and momentum balances equations through the screen model have been checked with experimental model, the test shows agreement [3]. The depth and velocity of flow through vertical angled wedge-wire fish screen study showed that the flow depth at any section is approximately constant and decreased towards the bypass located at the downstream end, the distribution of the resultant velocity and its components are uniform in the vertical direction [4]. Studying the practical uses of screens in open channels with normal flow velocity to find the head loss by calculating the pressure difference between upstream and downstream screens is predict for inclined screens, equation is produced as a function of flow properties and geometry of screens [5].

The effect of screen porosity on the dissipating performance of the screen using single wall, double parallel walls and triangular combination of two screen walls, it has been found that 40% porosity of screen walls can be used as effective energy dissipater [6], experimental work was carried for fixed gate opening and of 24.5 mm and the screen at a distance 1.25 m from the gate. Froude number in this study was between 4 and 13, the study showed that these screens produce free forced and in the same case submerged jumps. The study find that the flow after passing the screen is supercritical with Froude number equal 1.65 and water depth equal to 0.28 times of the subcritical sequent.

The effect of porosity and location of screens from the sluice gate have been successfully tested experimentally for a Froude number upstream between 5 and 18 [7], the screens with different porosities were anchored to the channel bottom at a distances relative to the gate opening X/D, the study concluded that performance of the screens increase with increasing Froude number, the optimum porosity is 40%, this porosity provides generally higher energy dissipation, performance and efficiency of the screens decreases with increase in X/D values, and double screens dissipate energy more than single screen for the same Froude number.

The effect of screen thickness, location and inclination on the energy dissipation for 40% porosity have been studied experimentally for Froude number vary between 5 to 24, the study showed that inclination of screen did not have any future positive effective on the energy dissipation compared to vertically placed screens [8].

Combination of two screen walls to construct triangular dissipater, the method of combination showed that the triangular screen configuration with the same opening geometry had no significant additional contribution on the energy dissipation as compared to vertically and inclination placed screens for Froude number between 7.5 and 25.5 [9]

The effect of tail water on energy dissipation by screens of 40% porosity, has also studied [10], it was found that for Froude number between 5 and 22,5 the tail water depth has not significant additional contribution on the energy dissipation.

In this experimental investigation the characteristics of holes shape, dimensions and the distance from the sluice gate was studied as a major parameters effecting the energy dissipation by the screens.

## 2 THEORETICAL BACKGROUND

The supercritical flow under sluice gates, could be forced to change his kinetic energy to other forms of energy, this could happened when it has impacted by wall screen, figure (1) shows the definition sketch of the phenomena and the depth of water upstream and downstream the screen.

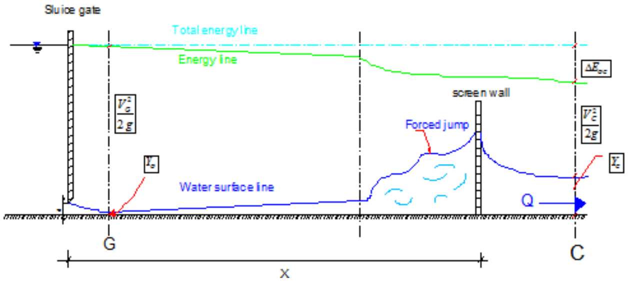


Figure (1) Definition sketch for the investigation

The quantity of energy dissipation between section G and section C on a horizontal bed is the different between the values of the specific energy in each of these sections, and after assuming the value of the energy coefficient αG and αc equal to one. The value of energy dissipated can be written as in equation (1) and (2).

$$\Delta E_{GC} = E_G - E_C \qquad \text{.........................} \quad (1)$$

$$\Delta E_{GC} = \left[ y_G + \alpha_G \frac{V_G^2}{2g} \right] - \left[ y_C + \alpha_C \frac{V_C^2}{2g} \right] \text{....} \,(2)$$

Where:
$\Delta E_{GC}$ = total energy loss between section G and section C.
$E_G$ = specific energy at section G,
$E_C$ = specific energy at section C.
$y_G$ = depth of water at the section G
$y_c$= depth of water at the section C
$V_G$ = velocity of water at the section G
$V_c$= velocity of water at the section C
$\alpha_G$ = energy coefficients at section G.
$\alpha_C$= energy coefficients at section C.

The contraction coefficient of the flow beneath the gate is equal to 0.625 of the gate opening [11], according to this investigation the depth of flow at section G can be written as in equation (3)

$$y_G = C_c \cdot D = 0.625 D \qquad \text{.......................} \quad (3)$$

Where:
D= sluice gate opening,
Cc=contraction coefficient

Referring to [12], the relative energy loss through classical hydraulic jump at Section G is given as:

$$\frac{\Delta E_{Classical\ jump}}{E_G} = \frac{2 - 2\left(\frac{y_{c\ \ classical}}{y_G}\right) + Fr_G^2\left[1 - \left(\frac{y_G}{y_{C\ \ classical}}\right)^2\right]}{2 + Fr_G^2} \qquad \text{..........} \quad (5)$$

and

$$\frac{y_G}{y_{C\ \ classical}} = \frac{1}{2}\left(\sqrt{1 + 8 Fr_G^2} - 1\right) \qquad \text{............} \quad (6)$$

Where:
$\Delta E_{\text{Classical jump}}$=energy loss at classical hydraulic jump
$y_{C\ \ \text{classica}}$l =subcritical (sequence) depth of classical hydraulic jump at section
$Fr_G$ = Froude number at section G.

According to Çakir (2003), the efficiency of the system (ηSys) referring to classical jump is given in equation (7):

$$\eta_{Sys} = \frac{\Delta E_{GC} - \Delta E_{Calssical\ jump}}{\Delta E_{Classica\ jumpl}} \qquad \text{........................} \quad (7)$$

Based on the above equations, the geometry of the experimental models and using dimensional analysis, the following functional relationship can be obtained.

$$\frac{\Delta E_{GC}}{E_G} = f\left(\frac{L}{y_G}, Fr_G, \frac{D}{y_G}, \frac{B}{y_G}, \frac{X}{y_G}, \frac{t}{y_G}, \frac{h}{y_G}, \frac{d_1}{y_G}, P, R_e,\right) \quad \text{........}(8)$$

Where:
D= Height of sluice gate opening L
B= Flume width L
X= Distance from the gate to the screen wall L
P= Porosity of the screen none
L= Length of square opening L
h= Side height of hexagonal opening L
d1=Diameter of circular opening L
t= Screen wall thickness L
$R_e$ = Reynolds number
$Fr_G$= Froude number

The values of Reynolds number is not affected due to relatively high Froude number covered on the experiments. The contraction ratio(D/$y_G$ ), width of the canal (B), thickness of the screen (t) and porosity are constant, so finally equation (8) can be written as in equation (9).

$$\frac{\Delta E_{GC}}{E_G} = f\left(\frac{X}{D}, \frac{L}{y_G}, \frac{h}{y_G}, \frac{d_1}{y_G}, Fr_G\right) \quad \text{........}(9)$$

## 3 EXPERIMENTAL WORK

The experimental investigation was carried out in a horizontal flume of working length 5 m, having a rectangular cross section of 0.45m height and 0.3m width. Accurate point gauge with venier scale reading to 0.1* 10-3 m was used for measurements of flow depth. The screen walls were made of aluminum plastic composite panel with dimensions of 30cm width, 50cm height, and 4mm thickness with a constant porosity of 40% for all three shape modules. The screens ware fixed at distance equal to 80 and 120 time the sluice gate opening, figure (2) shows photos for the screen and the dissipation of the energy.

Figure (2) Representation of the module

The required porosity of the screens was obtained using uniform triangular distribution for circular, square and hexagonal openings with different dimensions, the distance from center to center between two holes (d) was calculated. The shapes and the dimensions of the screen models are shown in figure (3) and table (1).
The calculated dimensions for 40% porosity in each sheet has been perforated by CNC machine to get reliable degree of accuracy for the hole shape and its dimension. The flow discharge has been changed by changing the head of water upstream the sluice gate for a constant gate opening. The main variables taken in the experimental work were h, d1, S, and X/D to compare between shapes, dimensions and position of the screens, figure (4) shows the details of the model tested.

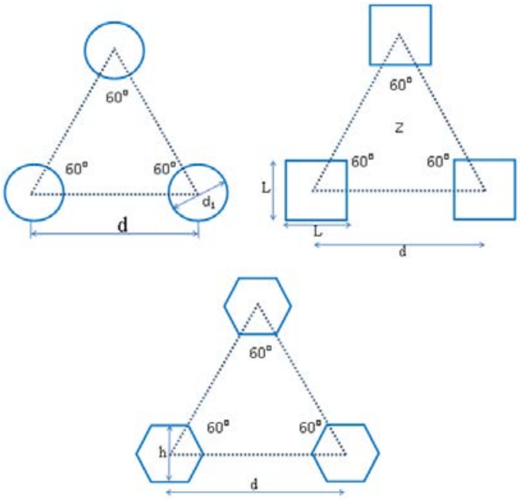


Figure (3) Representation screen opening

Table (1) Details of the screen opening models

| | L(cm) | | $d_1$ (cm) | | h(cm) | |
|---|---|---|---|---|---|---|
| | 1.20 | 1.60 | 1.35 | 1.81 | 1.29 | 1.72 |
| d | 2.04 | 2.72 | 2.04 | 2.72 | 2.04 | 2.72 |

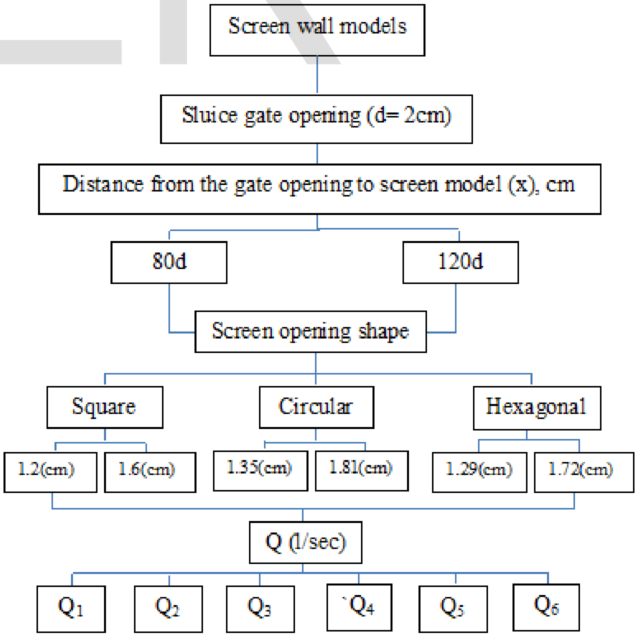
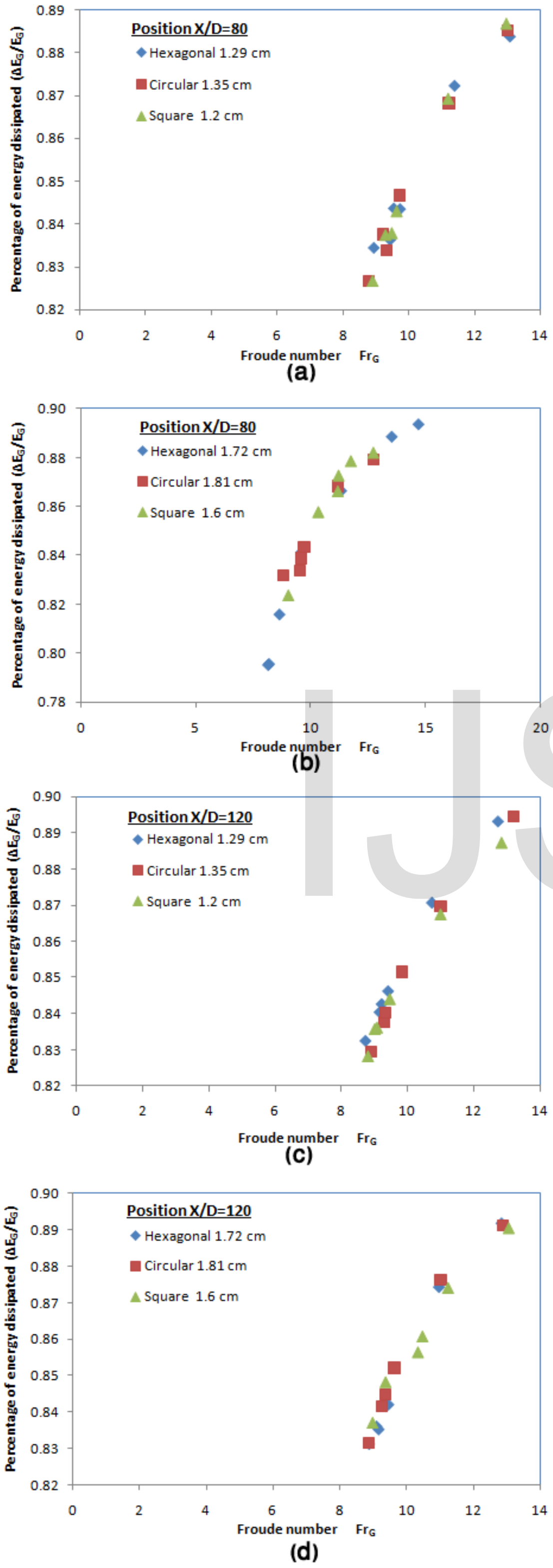


Figure (4) Details of the Model tested

## 4 RESULTS AND DISCUSSION

The data collected from the tests of the two positions of the screen and three shapes with two different dimensions models are presented in figure (5).



(a) (b) (c) (d)

Figure (5) Relation between the percentage of energy dissipation and Froude number

It is clear that the percentage of energy dissipation is increases with increase of the upstream Froude number ($Fr_G$) for all screen shapes openings and screen position. The increase of the energy dissipation is reasonable due to higher kinetic energy presented by the high values of Froude number.

Comparing the quantity of energy dissipated due to impact of screen to that coursed by classical jump for the same flow properties, it clear that screens contribute to dissipate more kinetic energy than the quantity dissipated by classical form of hydraulic jump. Figure (6 and 7) shows the deference in the energy dissipated between the plotted solid line of classical hydraulic jump and the screens.

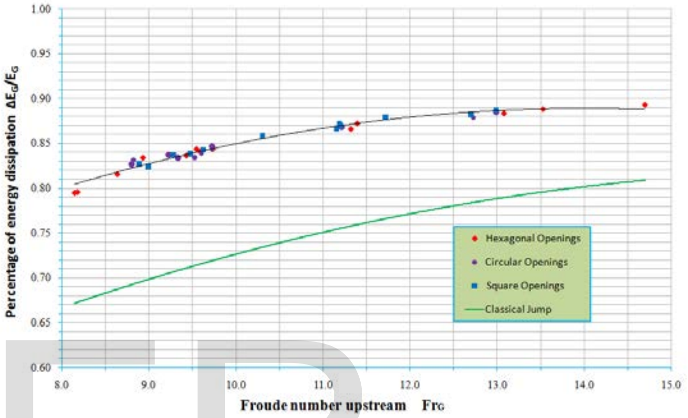


Figure (6) Relation between the percentage of energy dissipation and Froude number at X=80D

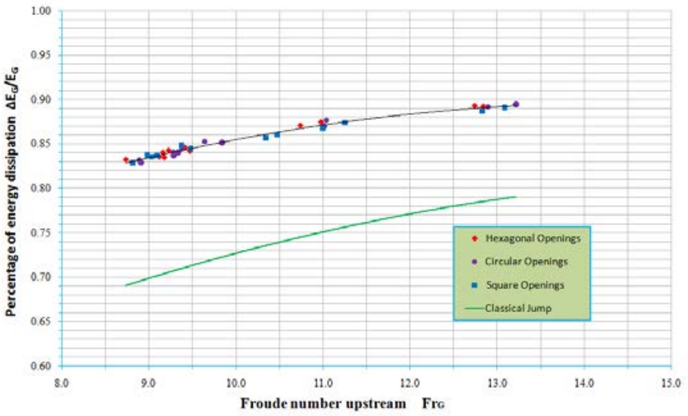


Figure (7) Relation between the percentage of energy dissipation and Froude number at X=120D

The calculated system efficiency (ηSys) from equation (7) is presented in figure (8), it clear that the system efficiency decreases with increases of Froude number for all screen shapes, dimensions and relative distance. It is also clear from figures (5 to 8) that the effect of shape, their dimensions and relative screen outlet distance (X/D) cannot be easily recognized.

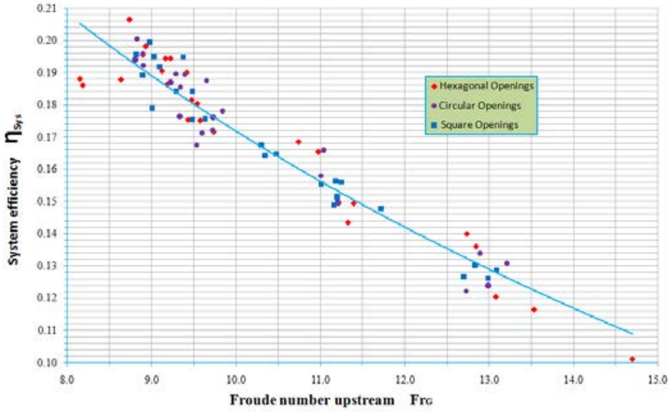


Figure (8) Relation between system efficiency and Froude number for all modules

The performance of screen in dissipating energy is better for a supercritical flow with lower values of Froude number. The descriptive analysis of the data, for the percentage of energy dissipated $\Delta E_{GC}/E_G$ varies in the range from 0.7951 to 0.8944, with Standard Error 0.0027539 and Standard Deviation 0.0235292. To find the mathematical relation of the percentage of energy dissipated with other dimensionless parameters, the total experimental measures and the calculated values of the dimensionless parameters in equation (9) were combined to carry statistical analysis for the data by using the facilities of the SPSS 17 Package. The correlation between the dependent variable $\Delta E_{GC}/E_G$ with the calculated dimensionless parameters was studied. It was found that the independent parameter ($Fr_G$) have a high significant correlation at the 0.01 level ( 2-tailed ) with positive Pearson Correlation factor 0.950, while correlation of the parameters ( $X/D$, $L/y_G$, $h/y_G$, $d_1/y_G$) with the percentage of energy dissipation isn't significant, table (2) shows the correlation.

Table (2) Correlation between dimensionless parameters

Correlations

| | | dE/EG | X/D | L/yG | h/yG | d1/yG | Fr(G) |
|---|---|---|---|---|---|---|---|
| dE/EG | Pearson Correlation | 1 | .077 | .127 | -.100 | -.013 | .950** |
| | Sig. (2-tailed) | | .519 | .285 | .398 | .916 | .000 |
| | N | 73 | 73 | 73 | 73 | 73 | 73 |
| X/D | Pearson Correlation | .077 | 1 | .007 | -.029 | .009 | -.082 |
| | Sig. (2-tailed) | .519 | | .952 | .806 | .942 | .489 |
| | N | 73 | 73 | 73 | 73 | 73 | 73 |
| L/yG | Pearson Correlation | .127 | .007 | 1 | -.489** | -.475** | .085 |
| | Sig. (2-tailed) | .285 | .952 | | .000 | .000 | .472 |
| | N | 73 | 73 | 73 | 73 | 73 | 73 |
| h/yG | Pearson Correlation | -.100 | -.029 | -.489** | 1 | -.489** | -.016 |
| | Sig. (2-tailed) | .398 | .806 | .000 | | .000 | .891 |
| | N | 73 | 73 | 73 | 73 | 73 | 73 |
| d1/yG | Pearson Correlation | -.013 | .009 | -.475** | -.489** | 1 | -.041 |
| | Sig. (2-tailed) | .916 | .942 | .000 | .000 | | .731 |
| | N | 73 | 73 | 73 | 73 | 73 | 73 |
| Fr(G) | Pearson Correlation | .950** | -.082 | .085 | -.016 | -.041 | 1 |
| | Sig. (2-tailed) | .000 | .489 | .472 | .891 | .731 | |
| | N | 73 | 73 | 73 | 73 | 73 | 73 |

**. Correlation is significant at the 0.01 level (2-tailed).

Regression Analysis of 17 different models is carried on by the same package. Two model have been employed, the linear and the power, which are presented in table (3) with their coefficient of determination. The power equations have a little bit better values of $R^2$. The Contribution of relative distance (x/D) slightly affects the power and linear models. The same conclusion can be addressed for the contribution of the other parameters in equation (9).

Table (3) The regression analysis models of the percentage of energy dissipated

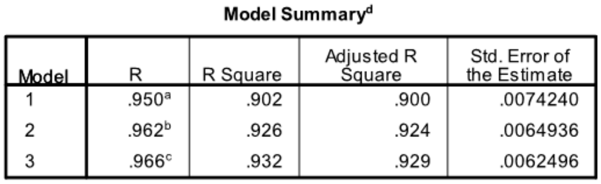
| No | Shape | Equation | $R^2$ |
|---|---|---|---|
| 1 | Circular | $\frac{\Delta E_{GC}}{E_G} = 0.692 + 0.014 Fr_G + 0.00014 \frac{X}{D}$ | 0.959 |
| 2 | Circular | $\frac{\Delta E_{GC}}{E_G} = 0.707 + 0.014 Fr_G$ | 0.937 |
| 3 | Circular | $\frac{\Delta E_{GC}}{E_G} = 0.519 Fr_G^{0.18} \cdot \left[\frac{X}{D}\right]^{0.017} \cdot \left[\frac{d_1}{y_G}\right]^{0.004}$ | 0.969 |
| 4 | Circular | $\frac{\Delta E_{GC}}{E_G} = 0.520 Fr_G^{0.18} \cdot \left[\frac{X}{D}\right]^{0.017}$ | 0.949 |
| 5 | Circular | $\frac{\Delta E_{GC}}{E_G} = 0.562 Fr_G^{0.18}$ | 0.946 |
| 6 | Hexagonal | $\frac{\Delta E_{GC}}{E_G} = 0.698 + 0.015 Fr_G + 0.0002 \frac{X}{D} - 0.025 \frac{h}{y_G}$ | 0.940 |
| 7 | Hexagonal | $\frac{\Delta E_{GC}}{E_G} = 0.667 + 0.014 Fr_G + 0.0003 \frac{X}{D}$ | 0.914 |
| 8 | Hexagonal | $\frac{\Delta E_{GC}}{E_G} = 0.703 + 0.014 Fr_G$ | 0.863 |
| 9 | Hexagonal | $\frac{\Delta E_{GC}}{E_G} = 0.471 Fr_G^{0.193} \cdot \left[\frac{X}{D}\right]^{0.032} \cdot \left[\frac{h}{y_G}\right]^{-0.031}$ | 0.959 |
| 10 | Hexagonal | $\frac{\Delta E_{GC}}{E_G} = 0.48 Fr_G^{0.15} \cdot \left[\frac{h}{y_G}\right]^{-0.28}$ | 0896 |
| 11 | Hexagonal | $\frac{\Delta E_{GC}}{E_G} = 0.55 Fr_G^{0.187}$ | 0.893 |
| 12 | square | $\frac{\Delta E_{GC}}{E_G} = 0.705 + 0.014 Fr_G$ | 0.948 |
| 13 | square | $\frac{\Delta E_{GC}}{E_G} = 0.56 Fr_G^{0.182}$ | 0.959 |
| 14 | square | $\frac{\Delta E_{GC}}{E_G} = 0.543 Fr_G^{0.181} \cdot \left[\frac{X}{D}\right]^{0.01} \cdot \left[\frac{L}{y_G}\right]^{-0.009}$ | 0.969 |
| 15 | All shapes | $\frac{\Delta E_{GC}}{E_G} = 0.705 + 0.014 Fr_G$ | 0.902 |
| 16 | All shapes | $\frac{\Delta E_{GC}}{E_G} = 0.684 + 0.015 Fr_G + 0.00018 \frac{X}{D}$ | 0.926 |
| 17 | All shapes | $\frac{\Delta E_{GC}}{E_G} = 0.686 + 0.015 Fr_G + 0.00018 \frac{X}{D} - 0.003 \frac{h}{y_G}$ | 0.932 |

It clear that bigger dimensions of hexagonal shape opening have an inversed affect on the quantity of the dissipated energy for the same value of porosity. The best and simplest general equation for predicting the value of percentage energy dissipated is the last one in the table (3), which has been found by the regression of the data of $\Delta E_{GC}/E_G$ associated with the dimensionless parameters using stepwise method, this method involving progressively the independent variables to enter the regression processing to formulating the the best model to determine statistical significance predictors in the equation. the stepwise method start the mathematical model with the higher correlated independent variable in the matrix at confidence level of 95%, after including three independent variables stopped with adjusted R square is 0.932 and standard Error of estimate equal to 0.0062496.

$$\frac{\Delta E_{GC}}{E_G}=0.686+0.015Fr_G+0.00018\frac{X}{D}-0.003\frac{h}{y_G} \quad ..... \quad (10)$$

The statistical analysis output details for the proposed equation (10) are shown in table (4) and table (5). The Graphical illustration of the normal P-P regression standardized residual is shown on figure (9)

Table (3) Stepwise regression analysis



**Model Summary**[d]

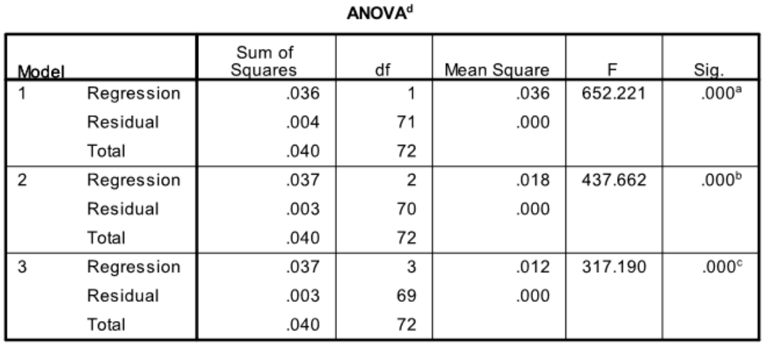
| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| 1 | .950[a] | .902 | .900 | .0074240 |
| 2 | .962[b] | .926 | .924 | .0064936 |
| 3 | .966[c] | .932 | .929 | .0062496 |

a. Predictors: (Constant), Fr(G)

b. Predictors: (Constant), Fr(G), X/D

c. Predictors: (Constant), Fr(G), X/D, h/yG

d. Dependent Variable: dE/EG



**ANOVA**[d]

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | .036 | 1 | .036 | 652.221 | .000[a] |
| | Residual | .004 | 71 | .000 | | |
| | Total | .040 | 72 | | | |
| 2 | Regression | .037 | 2 | .018 | 437.662 | .000[b] |
| | Residual | .003 | 70 | .000 | | |
| | Total | .040 | 72 | | | |
| 3 | Regression | .037 | 3 | .012 | 317.190 | .000[c] |
| | Residual | .003 | 69 | .000 | | |
| | Total | .040 | 72 | | | |

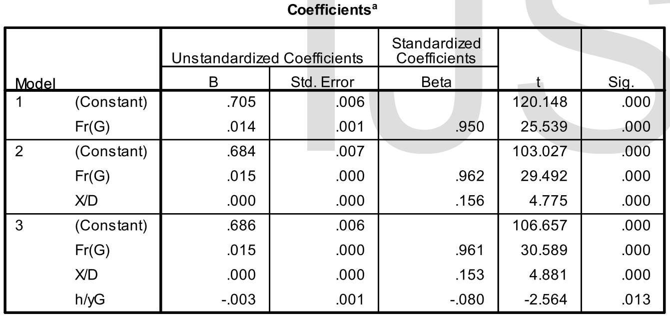
a. Predictors: (Constant), Fr(G)

b. Predictors: (Constant), Fr(G), X/D

c. Predictors: (Constant), Fr(G), X/D, h/yG

d. Dependent Variable: dE/EG

Table (4) Stepwise regression coefficients



**Coefficients**[a]

| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| 1 | (Constant) | .705 | .006 | | 120.148 | .000 |
| | Fr(G) | .014 | .001 | .950 | 25.539 | .000 |
| 2 | (Constant) | .684 | .007 | | 103.027 | .000 |
| | Fr(G) | .015 | .000 | .962 | 29.492 | .000 |
| | X/D | .000 | .000 | .156 | 4.775 | .000 |
| 3 | (Constant) | .686 | .006 | | 106.657 | .000 |
| | Fr(G) | .015 | .000 | .961 | 30.589 | .000 |
| | X/D | .000 | .000 | .153 | 4.881 | .000 |
| | h/yG | -.003 | .001 | -.080 | -2.564 | .013 |

a. Dependent Variable: dE/EG

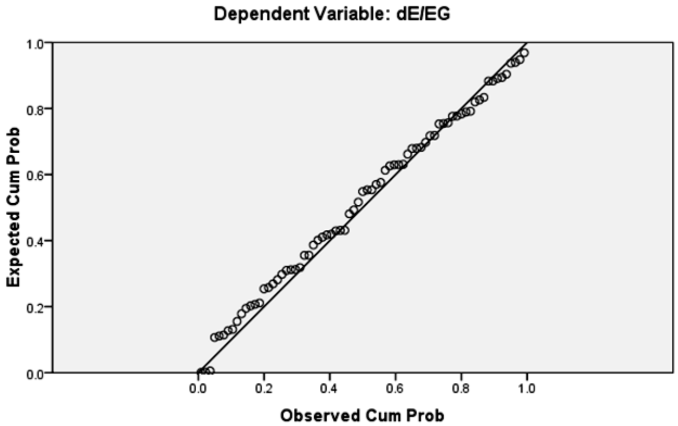


Figure (9) Normal P-P plot regression standardized residual

## 4 CONCLUSION

The super critical flow can be stilled by using screens. Some of the kinetic energy dissipated after the flow pass through the screen holes. From the statistical analysis of data within the experimental limitation, the following conclusions may fixed on the effect of screen position, shape and dimensions of openings on the energy dissipation.

1- The energy dissipated by three screens of different opening shapes and dimensions is more than the energy dissipated by classical hydraulic.

2- The percentage of energy dissipation is increases with the increase of Froude number at upstream, while the performance denoted by the system efficiency decreases for all screen configurations.

3- The effects of relative distance (X/D), shape of openings and dimensions on the percentage of energy dissipation are too small.

4- The increase in the length of hexagonal opening (h) in the screen has a negative effect on percentage of energy dissipation.

5- Within the limitations of the present experimental work the prediction of the percentage in the energy dissipation (Eq.10) is developed with mean percent error of 0.62%.

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