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# Energy Dissipation Through Pool Downstream Vertical Gates

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## ABSTRACT

The hydraulic jump downstream gates leads to increase the length of stilling basin for protection hydraulic structures from failures. In this paper, a new technique to increase energy dissipation between upstream and downstream through vertical gate with submerged hydraulic jump using a cylinder putting in pool is locating on stilling basin. This cylinder has different openings in solid and hollow cylinder with constant diameter and different heights. The results showed that in case of solid cylinder, the relative total energy dissipation is directly proportional to the initial Froude number and inversely proportional to the upstream and sequent Froude number. And vice versa in case of hollow cylinder, i.e. the relative total energy dissipation is inversely proportional to the initial Froude number and directly proportional to the upstream and sequent Froude number. Also, the maximum values of relative total energy dissipation occur when all the openings are open but the minimum values of it occurs when all the openings are close. Regardless of whether the cylinder is solid or hollow. Finally, in case of hollow cylinder, the relative height 2.4 gives the maximum values of relative total energy dissipation but the value of 1.0 gives the minimum ones. The main output of this paper that presence of openings in the cylinder has a clear effect on the energy dissipation.

**Keywords**: Relative Total Energy Dissipation, Vertical Gate, Openings, Solid and Hollow Cylinder

## 1. INTRODUCTION

A lot of research has studied theoretically and experimentally the energy dissipation through hydraulic structures to get maximum energy dissipation and minimum hydraulic jump. For energy dissipation below flow regulartors, Ead and Rajaratnam (1998) presented a novel design idea. It was proposed to use a double-leaf gate design rather than a single-leaf sluicegate.The investigation of Screen-type energy dissipation for hydraulic structures was done in (2000) by Rajaratnam, N., and Hurtig K. Cakir P. (2003) performed studies on screens to see how effective they are in dissipating energy. They also found that the amount of energy wasted was not greatly affected by the thickness of screens. The results of studies on the usage of vertical screens showed that variations in the number of screens and the shape of the square aperture had an effect, but the thickness of the screen had no effect on energy loss. Lozano et al. (2009) studied sluice gates in irrigation canals under submerged conditions. The effect of the contraction coefficient was studied and the energy loss was found to be insignificant for large submergences. No attempt was made to explicitly relate the effect of energy loss on the discharge coefficient. Hong et al. (2010) investigated the force and drop length downstream of a vertical drop with a positive slope. Equations were given to estimate the force and drop length, and it was demonstrated that as the bed slope grew, so did the drop length and force on the downstream bed. An equation for the discharge coefficient of sluice gates in rectangular channels under orifice-flow conditions (both free and submerged) was developed by Habibzadeh A. et al.

(2011) using a theoretical approach to account for the effects of energy dissipation between the upstream section of the gate and the vena contracta. Sadeghfam et al. (2014) examined two different porosity ratios in twin vertical screens for energy dissipation. They discovered that compared to either free or submerged hydraulic jumps, dual screens are substantially more effective in reducing energy. Daneshfaraz et al. (2017) quantitatively examined the energy loss brought on by the employment of vertical screens and a baffle block downstream of a gate. The findings showed that the block models dissipate more energy than the non-block versions. Abdelmonem Y. et al. (2018) investigated energy dissipation downstream sluice using a pendulum sill and found that the best location of the pendulum sill is in the first half of the hydraulic jump. Nasrabadi et al. (2021) examined the performance of the Group Method Data Handling (GMDH) and Developed Group Method of Data Handling (DGMDH) machine learning algorithms to predict the features of a submerged hydraulic jump of a sluice gate. Their research showed that both models could estimate relative submergence depth, jump length, and relative energy loss with a respectable degree of accuracy. Yoosef doost A. and Lubitz W. (2022) examined the efficacy of five models in identifying flow regime conditions, estimating the discharge coefficient (Cd), and determining flow rate. To determine Cd for energy-momentum considering losses (EML) and HEC-RAS models, new equation forms and techniques are proposed. Ujjawal K. and Parthajit R.. (2023) investigate the effectiveness of perforated screens as energy dissipater's in mixed triple wall mode in the case of small hydraulic structures. The Previous studies investigated energy dissipate through hydraulic structures to found solutions for dissipate hydraulic jump downstream this hydraulic structures, also present study investigated energy dissipate through a vertical gate between upstream and downstream using a cylinder putting in pool that is located on a stilling basin.

## 2. EXPERIMENTAL WORK

The experiment was conducted in the Hydraulic Engineering Laboratory at Benha University's Faculty of Engineering. The employed flume has the dimensions given in Figure 1 where: width is 0.4 m, height is 0.6 m, and length is 15.0 m. sample of experimental models hollow and solid cylinder with opening as shown in Figure 1. To measure the discharge that fed the flume, a flow meter was mounted. Table 1 defines the experimental results.

**Table: 1 Description of the experimental data**

| | | | |
|---|---|---|---|
| Discharge (Q) | 32 (L/s) | Initial depth of hydraulic jump ($y_1$) | 2 to 6 cm |
| Gate opening (a) | 5 cm | Sequent depth of hydraulic jump ($y_2$) | 15 to 20 cm |
| Water depth at upstream ($y_d$) | 15 to 20 cm | Initial Froude number of hydraulic jump ($F_1$) | 2 to 5 |
| Water depth at downstream ($y_u$) | 20 to 50 cm | Final Froude number of hydraulic jump ($F_2$) | 0.3 to 0.46 |
| Width of pool (w) | 30 cm | Height of pool (H) | 10 cm |
| Diameter of cylinder (d) | 10 cm | Height of cylinder (h) | 10 , 15 and 24 cm |
| Diameter of cylinder ( o ) | 1 cm | The pool distance from gate (L) | 30 cm |

**Figure 1: General view of the flume**

**Figure 2: Hollow and solid cylinder with opening**

## 3. DIMENSIONAL ANALYSIS

The dimensional analysis method for the experimental parameters was applied; Figure 3 shows the many factors that may be defined as functions of the following independent variables to effect the energy dissipation through the gate:

$$\frac{\Delta E_T}{E_u} = f\,(y_u, y_1, y_2, y_d, a, B, H, w, h, o, d, L, V, g, \rho, \mu) \quad (1)$$

By using (B, g and $\rho$) as repeated variables the Buckingham theorem is applied, the number of groups = 16-3 = 13 Π.

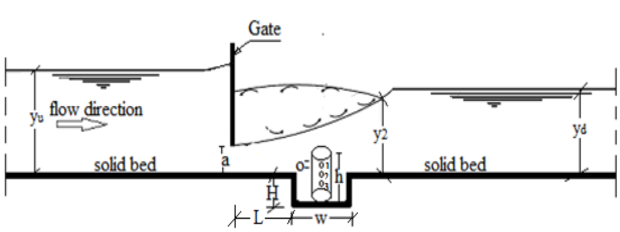
The following fundamental relationship can be obtained:

$$\frac{\Delta E_T}{E_u} = f\left(\frac{y_u}{B}, \frac{y_1}{B}, \frac{y_2}{B}, \frac{y_u}{B}, \frac{y_d}{B}, \frac{a}{B}, \frac{H}{B}, \frac{w}{B}, \frac{h}{B}, \frac{o}{B}, \frac{L}{B}, \frac{d}{B}, F_n, R_n\right) \quad (2)$$

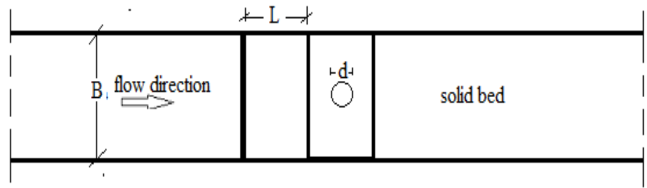
In which $R_n$ is Reynolds number, which assumed to be neglected, Eq. (2) may be rewritten as;

$$\frac{\Delta E_T}{E_u} = f\left(F_n, \frac{o}{h}, \frac{h}{H}, \frac{d}{W}, \frac{L}{B}\right) \quad (3)$$

Where: $\Delta E_T$: Loss of total Energy = $E_u - E_d$, $E_u$: Energy at the gate's upstream, $E_d$: Energy at the gate's downstream, H: height of the pool, $y_u$: water depth at upstream of gate, $y_1$: initial hydraulic depth of the water, $y_2$: depth of water at the subsequent hydraulic depth, $y_d$: depth of the water at the gate's downstream, d: the cylinder diameter, w: width of the pool, o: No. of openings in the cylinder, h: height of the cylinder, L: the pool distance from gate, a: gate opening , B: width of the flume, g: the gravitational acceleration , ρ : Water density, V: water velocity, μ: the fluid's dynamic viscosity, $F_n$: Froude Number.




(a) Elevation




(b) Plan

**Figure 3: Sketch of the definition for the experimental models (a) elevation and (b) plan**

## 4. ANALYSIS AND DISCUSSION

### 4.1 Effect of No. of Openings (O) in A Solid Cylinder on Energy Dissipation

The effect of number of openings (o) in a solid cylinder on dissipation of energy downstream gate contains on submerged hydraulic jump was investigated experimentally. The number of openings (o) = 1, 2 and 3 respectively are considered. The relationship between relative total energy dissipation ($\Delta E_T/E_u$) versus Froude number are shown in Figures. (4), (5) and (6). These figures illustrate that relative total energy dissipation increases with increasing initial Froude number and decreases with increasing upstream and sequent Froude number. Also, these figures show that the maximum values of relative total energy dissipation are obtained when all the openings are open and the minimum values are obtained when all opening are close. The previous result shows the effect of the presence of openings in the cylinder. Figure 7 confirms this result which showed relationship between relative total energy dissipation ($\Delta E_T/E_u$) and different No. of openings (o) in solid cylinder at $F_u$ = 0.12. Also, this figures clarifies that the relative total energy dissipation in case of all openings are open is higher with a percentage of 7% comparing with the case of all openings are close at the considered value of $F_u$ = 0.12.

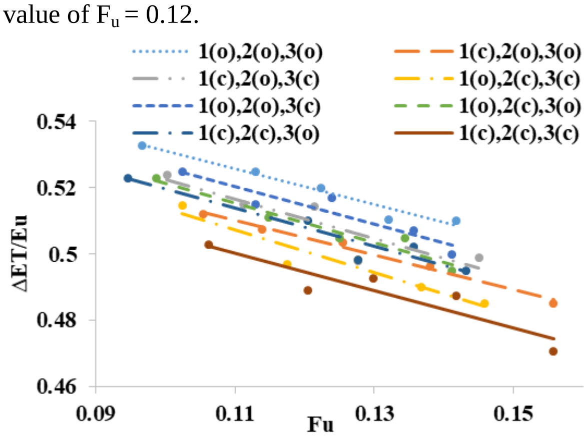



**Figure 4: Relationship between relative total energy dissipation ($\Delta E_T/E_u$) and upstream Froude number ($F_u$) with different No. of openings (o) in a solid cylinder**

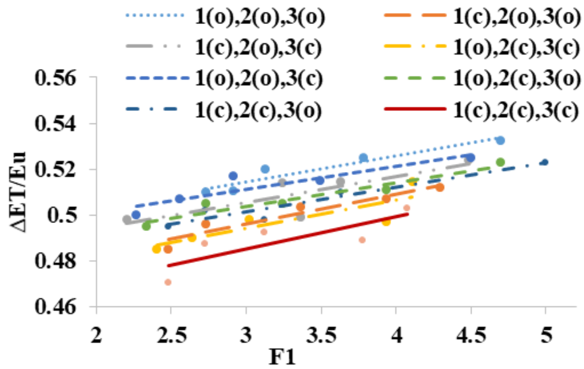



**Figure 5: Relationship between relative total energy dissipation ($\Delta E_T/E_u$) and initial Froude number ($F_1$) with different No. of openings (o) in a solid cylinder**

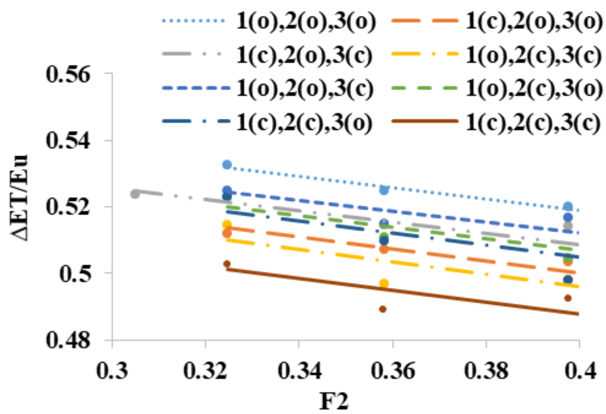



**Figure 6: Relationship between relative total energy dissipation ($\Delta E_T/E_u$) and sequent Froude number ($F_2$) with different No. of openings (o) in a solid cylinder**

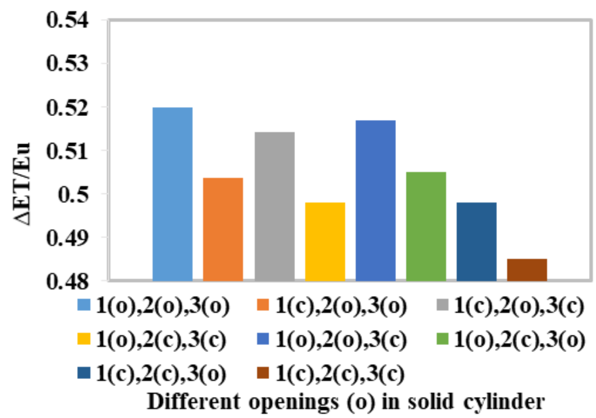



**Figure 7: Relationship between relative total energy dissipation ($\Delta E_T/E_u$) and different No. of openings (o) in a solid cylinder at $F_u = 0.12$**

## 4.2 Effect of No. of openings (o) in a hollow cylinder on energy dissipation

The effect of number of openings (o) in a hollow cylinder on dissipation of energy was investigated experimentally. The number of openings (o) = 1, 2 and 3 respectively are considered. The relationship between relative total energy dissipation ($\Delta E_T/E_u$) versus Froude number are shown in Figures. (8), (9) and (10). This figures clarify that the relative total energy dissipation is inversely proportional to the initial Froude number ($F_1$) and directly proportional to the upstream Froude number ($F_u$) and sequent Froude number ($F_2$), this means that the relative total energy dissipation increases with increasing upstream Froude number and final Froude number and decreases with increasing initial Froude number. Also, these figures show that the maximum values of relative total energy dissipation are obtained when all opening are open and the minimum ones are obtained when all openings are close. Figure 11 confirms this result which showed relationship between relative total energy dissipation ($\Delta E_T/E_u$) and different No. of openings (o) in solid cylinder at $F_u$ = 0.12. Also, this figure illustrates that the relative total energy dissipation in case of all openings are open is higher which a percentage 9% comparing with the case of all openings are close at the considered value of $F_u = 0.12$

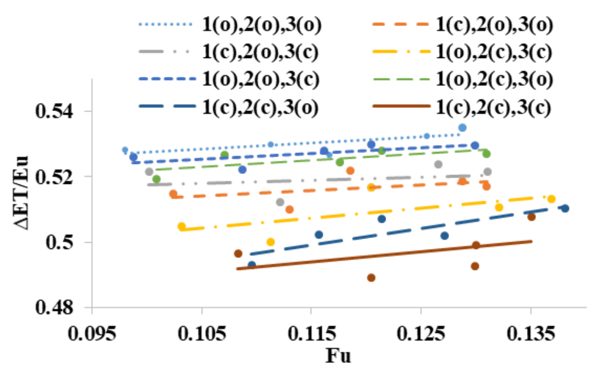



**Figure 8: Relationship between relative total energy dissipation ($\Delta E_T/E_u$) and upstream Froude number ($F_u$) with different No. of openings (o) in a hollow cylinder**

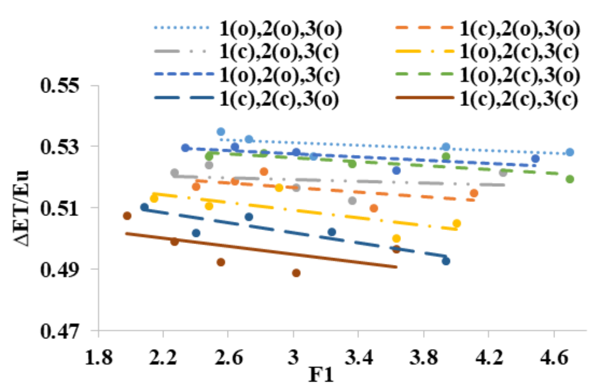



**Figure 9: Relationship between relative total energy dissipation ($\Delta E_T/E_u$) and initial Froude number ($F_1$) with different No. of openings (o) in a hollow cylinder**

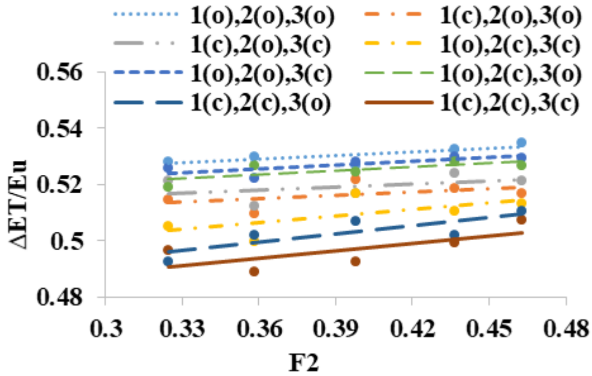



**Figure 10: Relationship between relative total energy dissipation ($\Delta E_T/E_u$) and sequent Froude number ($F_2$) with different No. of openings (o) in a hollow cylinder**

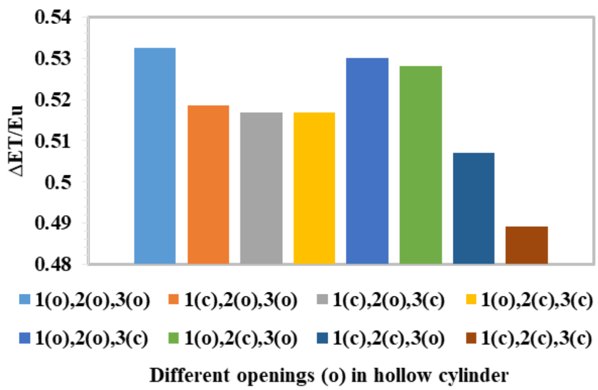



**Figure 11: Relationship between relative total energy dissipation ($\Delta E_T/E_u$) and different openings (o) in a hollow cylinder at $F_u = 0.12$**

### 4.3 Effect of Relative Height of the Hollow Cylinder on the Energy Dissipation

Effect of the relative height of the cylinder on the energy dissipation was studied in case of all opening are open with relative height (h/H) = 1, 1.5 and 2.4). Figures (12), (13) and (14) show the relationships between the relative total energy dissipation ($\Delta E_T/E_u$) and upstream, initial and sequent Froude number respectively. From these figures, it can be concluded that, the maximum values of relative total energy dissipation are obtained from the case of (h/H = 2.4) and the minimum ones are obtained from the case of (h/H = 1). This means increasing of the height of the cylinder leads to increasing of energy dissipation. Also, this figure clarifies that the case of (h/H = 2.4) gives relative total energy dissipation more than the case of (h/H = 1) with a percentage 6% for the case of $F_u$ = 0.12.Figure 15 confirms this result which showed relationship between relative total energy dissipation (ΔET/Eu) and different relative height (h/H) at $F_u = 0.12$

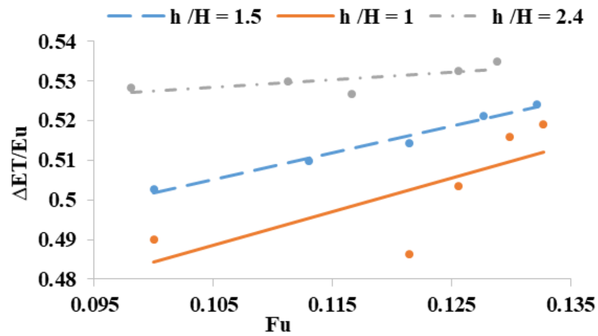



**Figure 12: Relationship between relative total energy dissipation ($\Delta E_T/E_u$) and upstream Froude number ($F_u$) with different relative height (h/H)**

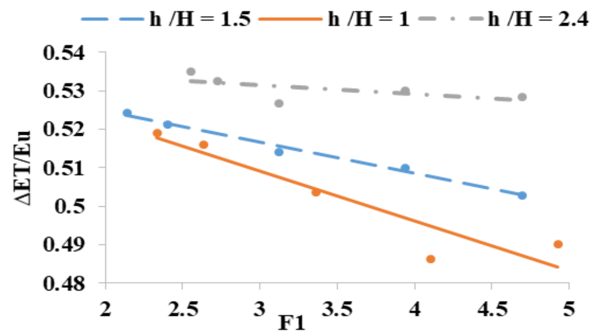



**Figure 13: Relationship between relative total energy dissipation ($\Delta E_T/E_u$) and initial Froude number ($F_1$) with different relative height (h/H)**

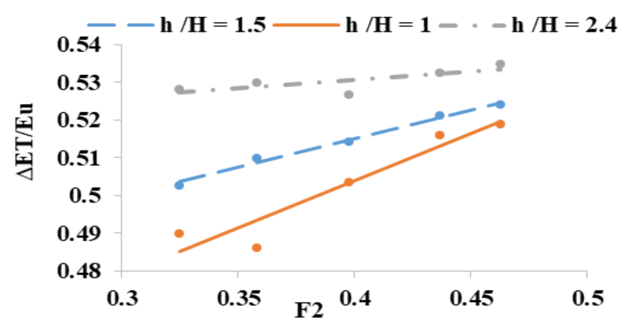



**Figure 14: Relationship between relative total energy dissipation ($\Delta E_T/E_u$) and sequent Froude number ($F_2$) with different relative height (h/H)**

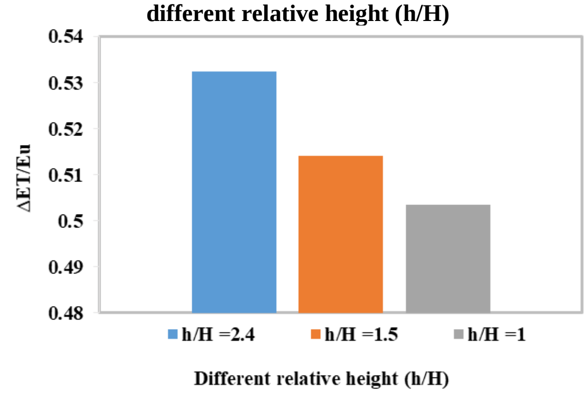



**Figure 15: Relationship between relative total energy dissipation ($\Delta E_T/E_u$) and different relative height (h/H) at $F_u = 0.12$**

### 4.4 Effect of The Cylinder on The Relative Total Energy Dissipation

To study the effect of the existence of the cylinder, as well as the effect of the cylinder body being solid or hollow, the case of the cylinder that gives the highest energy dissipation was chosen, which is that all openings are open, whether the cylinder is solid or hollow and compared them to the case without cylinder, when the values of upstream Froude number Fu = 0.1, 0.12 and 0.14 as shown in Figures (16), (17) and (18). These figures illustrate that the case of hollow cylinder dissipates the energy more than the case of solid cylinder and existence of the cylinder whether solid or hollow gives values of energy dissipation more than the case of without cylinder. From figure (18), it can be concluded that the existence of the solid cylinder dissipates the energy with a percentage 15% more than the case of without cylinder and 19% for the case of hollow cylinder at $F_u = 0.14$

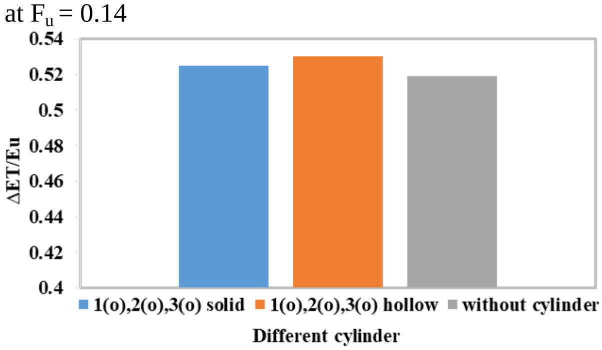



**Figure 16: Relationship between relative total energy dissipation ($\Delta E_T/E_u$) and different cylinder at $F_u = 0.1$**

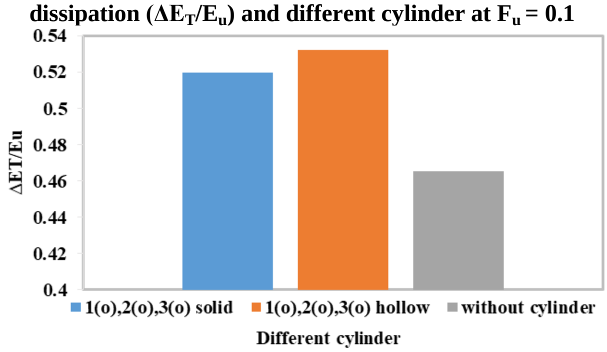



**Figure 17: Relationship between relative total energy dissipation ($\Delta E_T/E_u$) and different cylinder at $F_u = 0.12$**

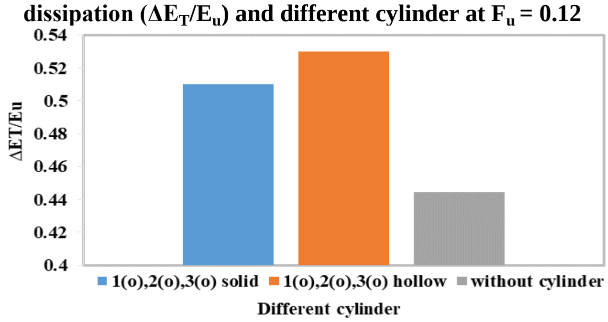



**Figure 18: Relationship between relative total energy dissipation ($\Delta E_T/E_u$) and different cylinder at $F_u = 0.14$**

## 5. COMPARISON of MEASURED DATA WITH OTHER STUDIES

It is important to compare of relative total energy dissipation for the different cases of this study with other searches. Fig. (19) Comparison of measured relative total energy dissipation ($\Delta E_T/E_u$) and initial Froude number ($F_1$) from others studies likes Rajaratnam (2000), Rasoul (2019) and Ujjawal (2023). From this figure obvious that the experimental data for this cases are acceptable compared to the equations collected from review.

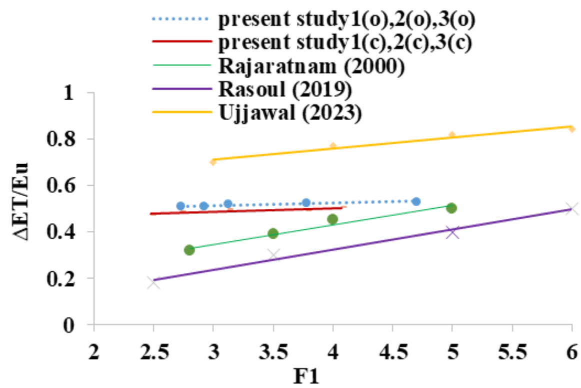



**Figure 19: Comparison of measured relative total energy dissipation ($\Delta E_T/E_u$) and initial Froude number ($F_1$) from others studies.**

## 6. CONCLUSION And RECOMMENDATION

The experimental study of energy dissipation led to the following conclusions:

1- For the solid cylinder, the relative total energy dissipation ($\Delta E_T/E_u$) increases with increasing initial Froude number ($F_1$) and decreases with increasing upstream Froude number ($F_u$) and sequent Froude number ($F_2$).

2- For the hollow cylinder, the relative total energy dissipation ($\Delta E_T/E_u$) decreases with increasing initial Froude number ($F_1$) and increases with increasing upstream Froude number ($F_u$) and sequent Froude number ($F_2$).

3- The maximum values of relative total energy dissipation are obtained when all openings are open and the minimum ones are obtained when all openings are close regardless of whether the cylinder is solid or hollow.

4- For the hollow cylinder, increasing the relative height of the cylinder (h/H) leads to increasing the relative total energy dissipation.

5- Existence of the cylinder in the pool whether solid or hollow gives values of energy dissipation more than the case of without cylinder.

6- The hollow cylinder dissipates the energy more than the solid cylinder.

7- In case of hollow cylinder, the relative height 2.4 gives the maximum values of relative total energy dissipation but the value of 1.0 gives the minimum ones.

8- Present study agree well with other searches and give good result.

The following points are recommended for future studies:

1- The effect of changing gate opening.

2- The effect of dimensions of pool.

3- Appling this result on scour downstream hydraulic gats.

4- Appling this research on program hydraulic.

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**Credit Authorship Contribution Statement**

**Tarek Hemdan Nassralla:** Methodology, review, editing and supervision.

**Ahmed Shawky Mohamed Awwad:** conceptualization, original draft, supervision, review and editing.

**Declaration of competing Interest**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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