# Experimental study of the effect of horizontal screen diameter on hydraulic parameters of vertical drop

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## ABSTRACT

The horizontal screen is one of the energy dissipater structures used on the brink of vertical drop. These structures increase the energy dissipation and the turbulence in the flow by causing the air entrainment. In the present study, the effect of the diameter of the screen with constant porosity at three different diameters on the hydraulic parameters of the vertical drop was investigated. The experiments were performed in the relative critical depth range of 0.13 to 0.39. The results showed that by increasing the relative diameter of the horizontal screen, the relative wetting length and turbulence length increased, the residual energy remained constant and the pool depth decreased. Compared to the stilling basin, the horizontal screen significantly reduces turbulence length and residual energy. The results also showed that the application of horizontal screens at the brink of the drop, with and without a downstream rough bed, could be a suitable alternative for a stilling basin.


**Key words** | air entrainment, energy loss, mixing length, screen diameter, vertical drop

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## HIGHLIGHTS

- The horizontal screen is one of the energy dissipator structures used on the brink of vertical drop and increase the energy dissipation and the turbulence in the flow by causing the air entrainment.
- The diameter of the screen holes plays a role in the increasing of the mixing length.
- Vertical drop equipped with a horizontal screen reduces the residual relative energy by 30% compared to the stilling basin.

## INTRODUCTION

Vertical drops also known as a grade control, or over-fall, is typically built in irrigation channels to pass water to a lower elevation or used in mountainous areas to reduce the steep slopes. Flow downstream of the drops, due to the slope, has a destructive kinetic energy. If this destructive energy is not controlled and reduced, downstream structures will be exposed to erosion and destruction. A hydraulic jump in the stilling basin is therefore commonly used to reduce energy (Fathi-Moghadam *et al.* 2017; Kabiri-Samani *et al.* 2017).

The first basic studies on vertical drops have been made in 1932 by Bakhmeteff (1932). He presented an equation to calculate the downstream water depth of a drop by assuming flow momentum, a hydrostatic distribution of pressure and a uniform distribution of velocity. Rouse (1936) developed an equation to estimate the discharge in a vertical drop. Subsequently, extensive experimental studies have been performed to characterize the flow over a simple vertical drop. Many of these researchers investigated the total energy loss and the hydraulic parameters for plain vertical



doi: 10.2166/ws.2021.077

drops (White 1943; Rand 1955; Akram Gill 1979; Rajaratnam & Chamani 1995; Chamani *et al.* 2008). Esen *et al.* (2004) studied the energy dissipation of vertical drops with several steps considering different downstream dimensions: as the step height increased, the energy loss and the drop vertical downstream depth increased. Hong *et al.* (2010) measured the force and drop length with a positive slope downstream of a vertical drop. They provided equations for estimating the force and drop length and showed that by increasing the bed slope, the drop length and force on the downstream bed increased. Liu *et al.* (2014) investigated the influence of a positive slope upstream of a vertical drop. Their results revealed that the brink depth, the pool depth, and the angle of the falling jets decrease with such slopes. The influence of tailwater depth on the vertical hydraulic performance of the vertical drop equipped with grid dissipaters was also studied experimentally by Sharif & Kabiri-Samani (2018). The results showed that as the tailwater depth increases, air entrainment decreased.

The first studies on screens were performed by (Rajaratnam & Hurtig 2000) as energy-decreasing devices. Çakir (2003) carried out experiments on screens and showed that the use of screens for energy dissipation is effective. They also found that the thickness of the screens has an insignificant effect on energy dissipation. Studies were also carried out on the use of vertical screens; the results showed that the thickness of the screen had no effect on the energy loss but modifications in the number of screens and the shape of the square aperture had an impact (Aslankara 2007; Mahmoud *et al.* 2013; Sadeghfam *et al.* 2019). Sadeghfam *et al.* (2014) studied dual vertical screens for energy dissipation with two different porosity ratios. They found that dual screens are much more able to reduce energy compared to either free or submerged hydraulic jumps. Daneshfaraz *et al.* (2017) numerically investigated energy dissipation caused by the use of vertical screens along with a baffle block downstream of a gate. The results revealed that the block models have more energy dissipation than the non-block models.

Recently, the application of a horizontal screen at the brink of a vertical drop has been considered as a horizontal dissipater. Air entrainment is one of the factors commonly used for energy loss. These plates increase the energy loss by creating several falling jets and increasing turbulence downstream of the vertical drop. Screens on a vertical drop brink were studied by Kabiri-Samani *et al.* (2017). The results of their study revealed that when a vertical drop is equipped with screens, there is a decrease in the total length of the stilling basin downstream of the structures by about 60–75%. Sharif & Kabiri-Samani (2018) also investigated the effect of tailwater depth on a vertical drop equipped with a screen. The results showed that by increasing the tailwater depth, air entrainment decreases and the relative pool depth increases. Hasanniya (2019) investigated the hydraulic parameters of a vertical drop equipped with a horizontal screen with the subcritical flow. The results revealed that the relative depth of the pool, the relative downstream depth, and reduction in the total energy of the system increase.

From this prior research, it is evident that the simultaneous application of a vertical drop and a horizontal screen can lead to a significant increase in energy loss downstream of these structures. Anyway, there is still a significant need to better understand and analyze the geometric parameters affecting the hydraulic performance of a horizontal screen. Consequently, the current study aims to investigate the performance of the vertical drop equipped with a horizontal screen with constant porosity at three different diameters of holes. To validate the obtained results, the current study is also compared with previous research data.

## DIMENSIONAL ANALYSIS

Figure 1 is prepared to illustrate physical and hydraulic parameters of the flow for a vertical drop equipped with horizontal screens; these parameters are indicated in Equation (1):

$$f_1(Q, H, P, y_0, y_c, y_1, y_p, L_{wet}, L_D, D, E_0, E_1, \rho, \mu, g) = 0 \quad (1)$$

where $Q$ is the flow discharge, $H$ is the vertical drop height, $P$ is the porosity of screen, $h$ is the drop height, $y_0$ is the upstream depth, $y_c$ is the critical depth ($y_c = (q^2/g)^{1/3}$), $y_b$ is the brink depth, $y_1$ is the downstream depth, $y_p$ is the pool depth. $L_{wet}$ is the wetted length of the screen, $L_D$ is the mixing length of the pool, $D$ is the diameter of hole in screen, $E_0$ is the total energy upstream of the drop, $E_1$ is the specific energy downstream of the drop, $\rho$ is the density of water, $\mu$ is the dynamic viscosity and $g$ is the gravitational acceleration.

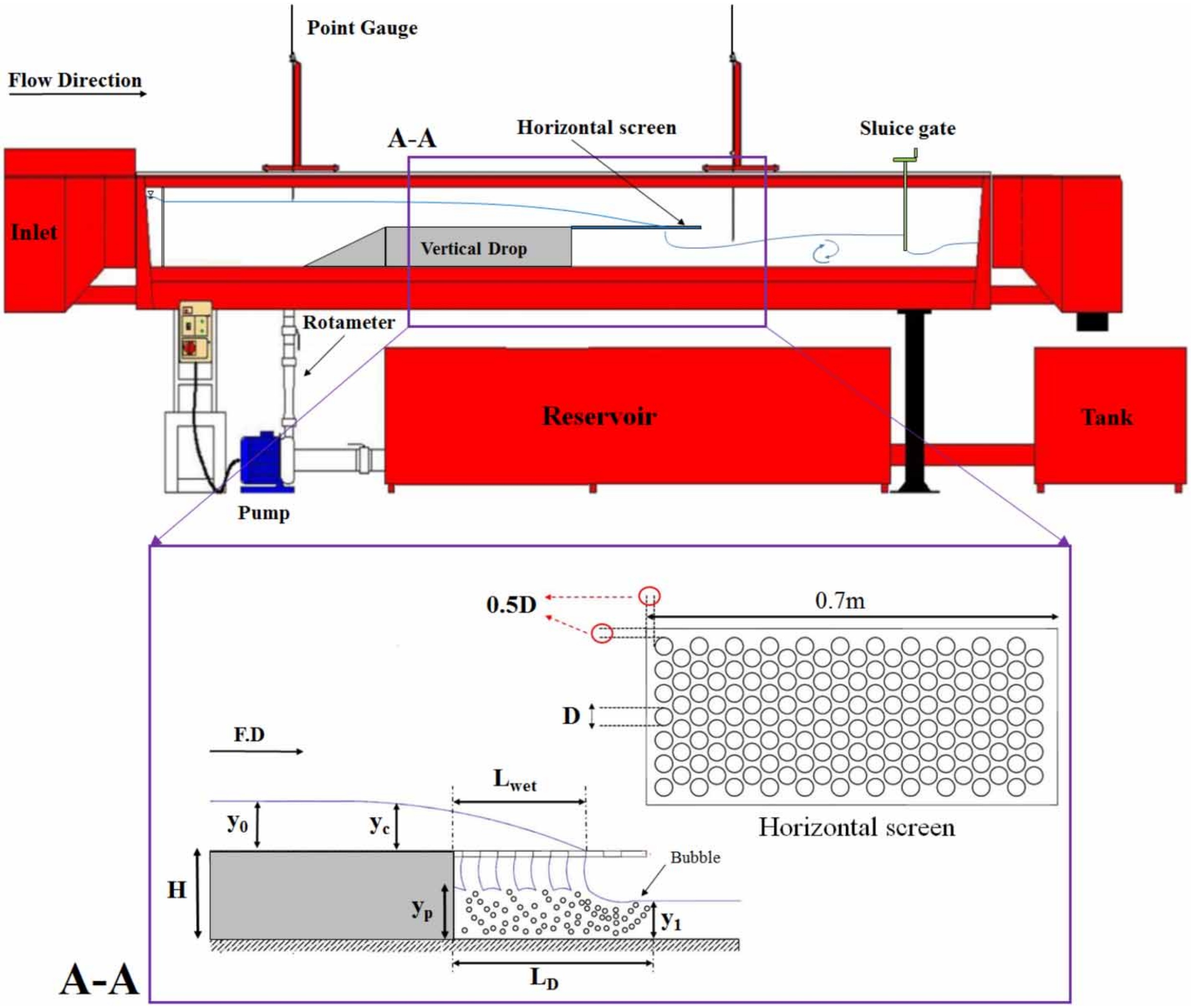


**Figure 1** | Illustration of the flow features and view of the test section and flumes.

Using the $\pi$-Buckingham's theorem and with $\rho$, $g$, and $H$ as repeated variables, the relative mixing length of the pool was obtained on the basis of the independent dimensionless parameters in Equation (2):

$$\frac{L_D}{H} = f_2\left(\mathrm{Re}_0, Fr_0, P, \frac{y_c}{H}, \frac{D}{H}\right) \tag{2}$$

By applying the same method, Equation (3) was obtained for the wetted length of horizontal screens, the depth of the pool and the normalized residual energy:

$$\frac{L_{wet}}{y_c}, \frac{y_p}{H}, \frac{E_1}{E_0} = f_3\left(\mathrm{Re}_0, Fr_0, P, \frac{y_c}{H}, \frac{D}{H}\right) \tag{3}$$

Here, $Re_0$ is the upstream Reynolds number, $Fr_0$ is the upstream Froude number, $D/H$ is the relative diameter of hole in screen, $y_p/H$ is relative pool depth, $y_c/H$ is relative critical depth, $L_{wet}/y_c$ is relative wetting length of screen, $L_D/H$ is relative drop length and $E_1/E_0$ is is the normalized residual energy. Since the upstream Reynolds number is between 4,879 and 18,920, the flow is quite turbulent and the effect of the dynamic viscosity and the Reynolds number can be neglected (Di Francesco *et al.* 2015; Biscarini *et al.* 2016; Mahtabi *et al.* 2020). According to the study of Daneshfaraz *et al.* (2020c and 2021), the porosity of horizontal screen has no effect on the relative residual energy. Moreover the 50% porosity of the plates leads to a wetting length of screen and a mixing length of the pool smaller than a 40% porosity one; therefore in the present study, the porosity of horizontal screen was considered to be 50%. The flow upstream of the vertical drop is subcritical and the Froude numbers are low ($0.69 \leq Fr_0 \leq 0.86$), so the effect of this parameter on the Equations (2) and (3) is neglected (Azamathulla & Ahmad 2012; Kabiri-Samani et al. 2017). Finally, Equations (4) and (5) are modified as follows:

$$\frac{L_D}{H}, \frac{y_p}{H}, \frac{E_1}{E_0} = f_4\left(\frac{y_c}{H}, \frac{D}{H}\right) \quad (4)$$

$$\frac{L_{wet}}{y_c} = f_5\left(Fr_0, \frac{y_c}{H}, \frac{D}{H}\right) \quad (5)$$

## MATERIALS AND METHODS

### Experimental setup

The experiments were performed in a horizontal, rectangular cross section channel with Plexiglas walls and with length, width, and height of 5, 0.3, and 0.45 m, respectively. The vertical drop height and length were $H = 0.15$ m and $L = 1.20$ m. Polyethylene horizontal screen of 1 cm thickness and dimensions with $0.3 \times 0.7$ m spanned the width of the channel. The screens included a zigzag of circular openings with constant porosity at three diameters of 1, 2 and 3 cm. At the inlet of the channel, there is a screen that eliminates the flow turbulence and the flow slowly enters the laboratory flume. With plexiglass, the influence of sidewall effects is considered to be negligible based upon the findings of Johnson (1996) and Moradinejad et al. (2019). Channel flow was measured by two pumps each at a maximum discharge of 7.5 L/s by two valves connected to two rotameters with an accuracy of ±2%, installed at the pump outlet. To ensure steady flow, vertical drop was installed 1.5 m downstream of the inlet tank. At the inlet of the channel, there is a screen that eliminates the flow turbulence and the flow slowly enters the laboratory flume. In total, 42 experiments were performed to investigate the research objectives. Figure 1 illustrates the experimental model of the present study. After stabilizing the flow conditions, the upstream depth, wetted length of the screen, mixing length of the pool, depth of the pool, and depth downstream were measured. The flow depth for both the upstream and downstream sections, was determined by a gauge point mounted on the flume top with an accuracy of ±1 mm. This measuring instrument was adopted from previous studies, for example, Daneshfaraz et al. (2020a; 2020b) and Ghaderi et al. (2020a; 2020b) and studies. To record the upstream flow depth, the gauge point was positioned at 3 H to 4 H (Ackers et al. 1978; Ghaderi et al. 2020c). Also, the flow depth was recorded downstream of the vertical drop at a distance of 1 m. In total, the depth at five locations was measured and the average value was used. A ruler with a precision of 1 mm was used to measure the respective lengths. Figure 2 illustrates a flow structure of the experimental model and the investigated ranges of the parameters are presented in Table 1.

### Calculations

The downstream Froude number ($Fr_d$) is calculated by using Equation (6) Rand (1995):

$$Fr_d = \left(\frac{y_c/H}{y_1/H}\right)^{1.5} \quad (6)$$

Prior researchers, for instance Esen et al. (2004) have presented their studies using the relative downstream depth as in Equation (7).

$$\frac{y_1}{H} = 0.4824\left(\frac{y_c}{H}\right)^{1.1854} \quad (7)$$

The Froude number of downstream of the plain vertical drop can be therefore expressed as:

$$Fr_d = 2.985\left(\frac{y_c}{H}\right)^{-0.278} \quad (8)$$

In the present study, the relative critical depth range is between 0.13 and 0.39, so the range of the downstream Froude number of plain vertical drop is 3.9 to 5.3. If a Type I Stilling basin downstream of the drop is used to dissipate the flow energy, the total drop length is obtained from

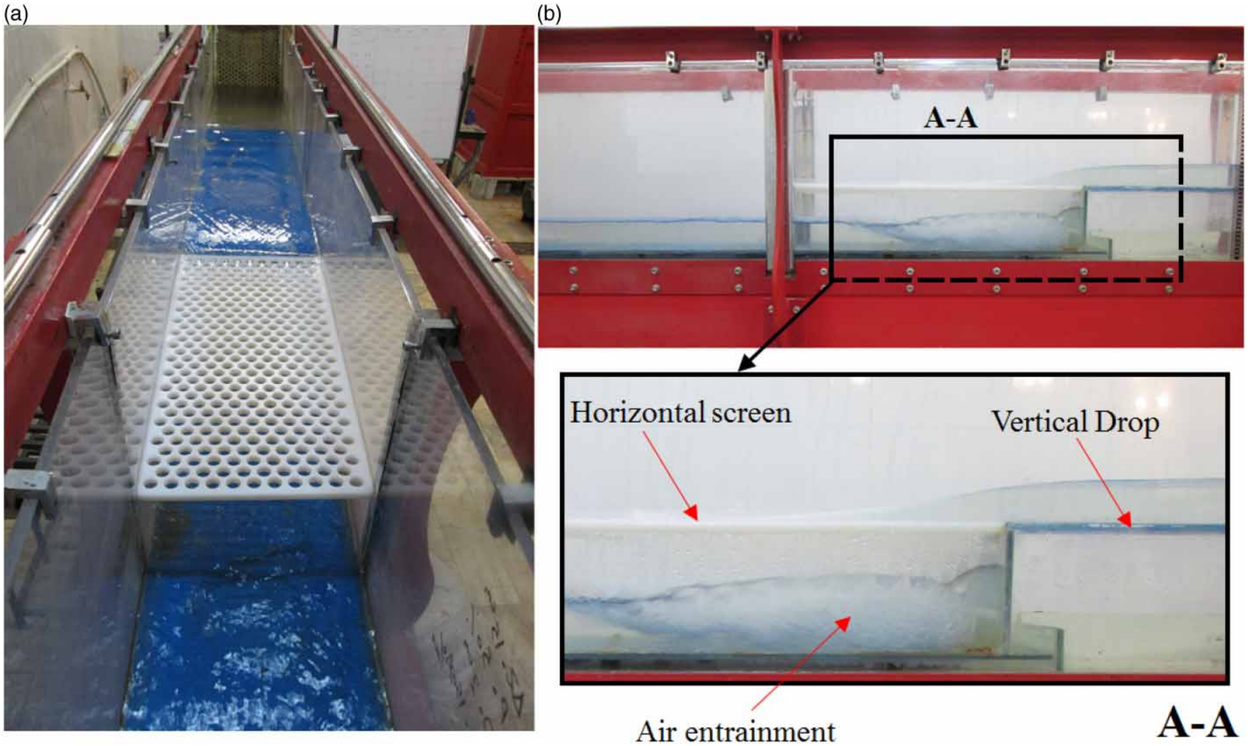


**Figure 2** | Flow structure of the experimental model of the present study (a) Top view (b) Side view.

**Table 1** | Investigated ranges of parameters

| | Parameters | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **D/H** | **Q (L/s)** | **$Fr_0$** | **$y_0$ (cm)** | **$y_1$ (cm)** | **$y_c$ (cm)** | **$y_p$ (cm)** | **$L_D$ (cm)** | **$L_{wet}$ (cm)** |
| 0.067 | 2.5–13.5 | 0.69–0.86 | 2.45–6.50 | 2.6–7.1 | 1.92–5.86 | 3.7–10.3 | 16–49 | 8–41 |
| 0.133 | 2.5–13.5 | 0.69–0.86 | 2.45–6.50 | 2.8–7 | 1.92–5.86 | 3.5–9.8 | 21–58 | 8.5–45 |
| 0.2 | 2.5–13.5 | 0.69–0.86 | 2.45–6.50 | 2.8–7.1 | 1.92–5.86 | 3.2–9.8 | 24–62 | 9–49.5 |

Equation (9) (see in Figure 3):

$$\frac{L_D}{H} = \frac{L_{ds}}{H} + \frac{L_b}{H} \tag{9}$$

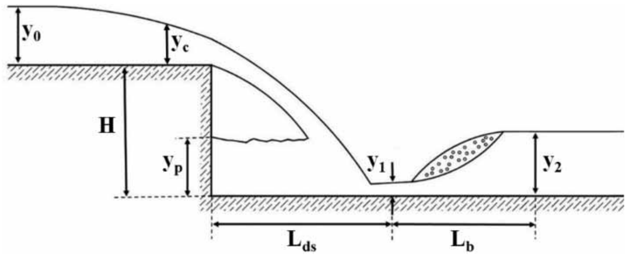


**Figure 3** | Vertical drop schematics equipped with a downstream stilling basin.

In the above equation, $L_{ds}/H$ and $L_b/H$ are the relative lengths of the plain vertical drop and the stilling basin downstream of the vertical drop, respectively. They can be calculated from the following equations:

$$\frac{L_{ds}}{H} = 4.3\left(\frac{y_c}{H}\right)^{0.81} \tag{10}$$

$$\frac{L_b}{H} = \frac{220 y_1 \tanh\left(\frac{Fr_d - 1}{22}\right)}{H} \tag{11}$$

## RESULTS AND DISCUSSION

In order to validate the results of a vertical drop, results from the present study were compared with those of Rajaratnam & Chamani (1995) (Figure 4), showing a good agreement. Moreover, the performance criteria (the determination coefficient ($R^2$) and the normalized root-mean-square error (NRMSE)) are calculated and presented in Table 2.

The existence of horizontal screens, with turbulence in the falling water jet and air entrainment, causes a loss of the jet. The wetted length, mixing length, pool length and residual downstream energy were measured and calculated.

### Relative wetted length

The length of the screen that the flow passes through its holes is called the wet length of the screen (see Figure 5). Since the relative wetted length ($L_{wet}/y_c$) can be used to optimize vertical drops with horizontal screens, it is important to investigate the influence of this parameter. Figure 6 shows the relative wetted length versus the Froude number taking in account three relative diameters of the screen porosities.

It can be seen that as the upstream Froude number increases, the flow velocity increases at the screen. Consequently, there is less flow through each grid opening and the wetted length of the screen for three relative diameter of hole in screen increases. It is also observed that as the relative diameter of the horizontal screens increases, the relative wetted length increases. Therefore, it can be claimed that in the constant porosity of the screen, by increasing the diameter of the screen holes, the total circumference of the screen holes decreases and the relative wetted length increases. Therefore, similar to the case of nonlinear weir (i.e. labyrinth weir), with decreasing the circumference of the screen holes, the flow rate through them decreases and the wetting length increases (Abbasi *et al.* 2021). The results show that the relative wetted length of the screens with a relative diameter of 0.133 and 0.2 increases by 11 and 18.5%, respectively, compared to the screen with a relative diameter of 0.067.

**Table 2** | Performance metrics related to comparison of the present results with those of the Rajaratnam & Chamani (1995)

| Comparison parameters | $R^2$ | NRMES |
|---|---|---|
| $y_p/H$ | 0.925 | 0.037 |
| $E_1/E_0$ | 0.980 | 0.01 |

Equation (12) was used to estimate the relative wetted length of the horizontal screens with three relative screen diameters of the present study.

$$\frac{L_{wet}}{y_c} = 16.03 Fr_0^{2.415} \left(\frac{D}{H}\right)^{0.153} \quad (12)$$

Equation (12) leads to a determination coefficient ($R^2$) and normalized root mean square error (NRMSE) of 0.96 and 0.023, respectively. This equation estimates laboratory

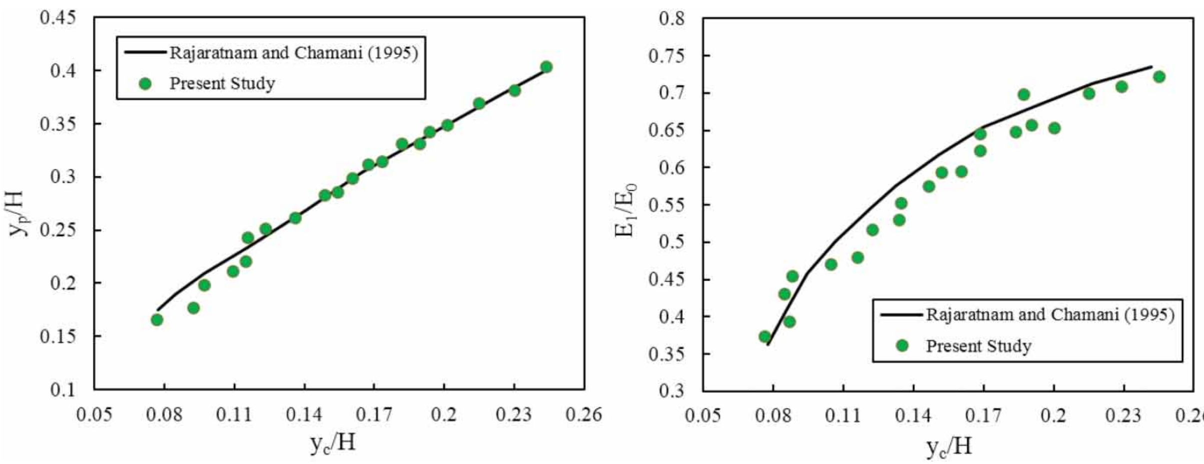


**Figure 4** | Comparison of the relative pool depth for a vertical drop and normalized residual energy of the present study with the results of Rajaratnam & Chamani (1995).

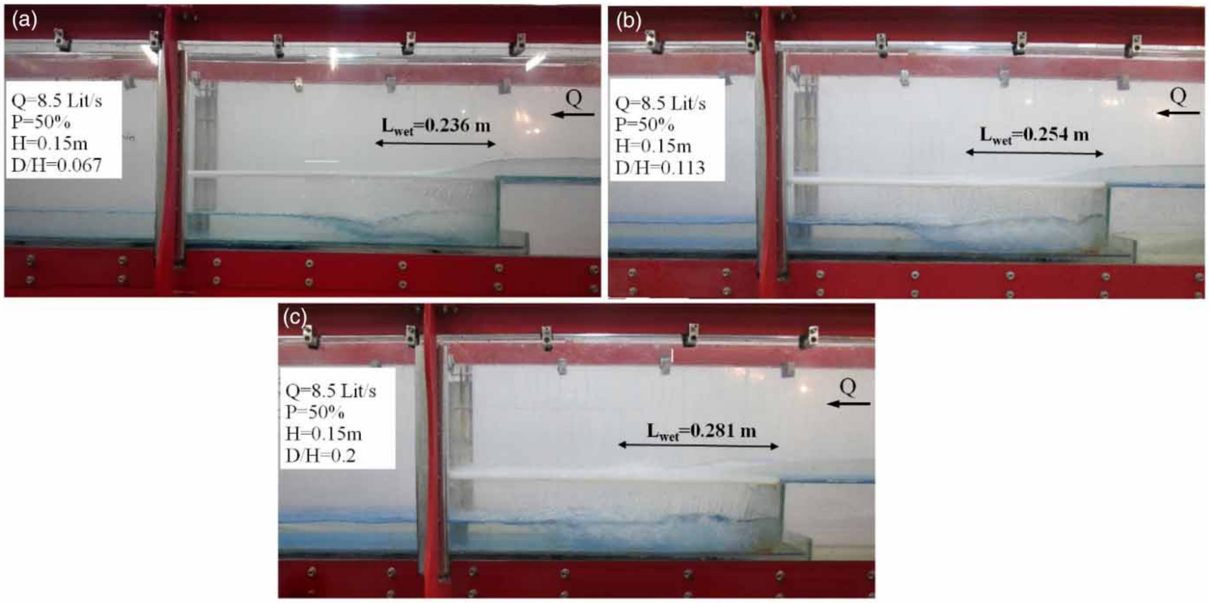


**Figure 5** | The wetted length on the vertical drop equipped with a horizontal screen with Q = 8.5 Lit/s (a) D/H = 0.067 (b) D/H = 0.113 (c) D/H = 0.2.

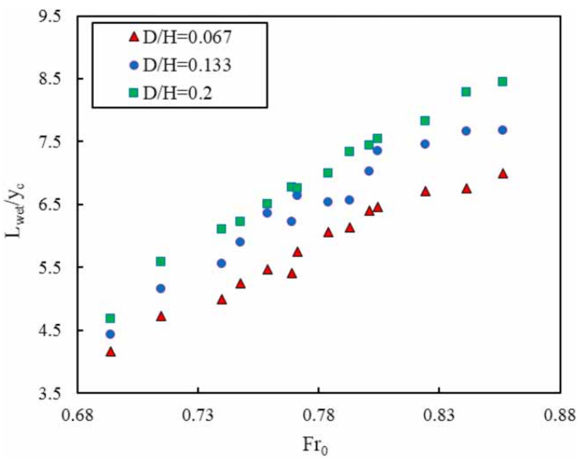


**Figure 6** | Relative wetted length versus the Froude number.

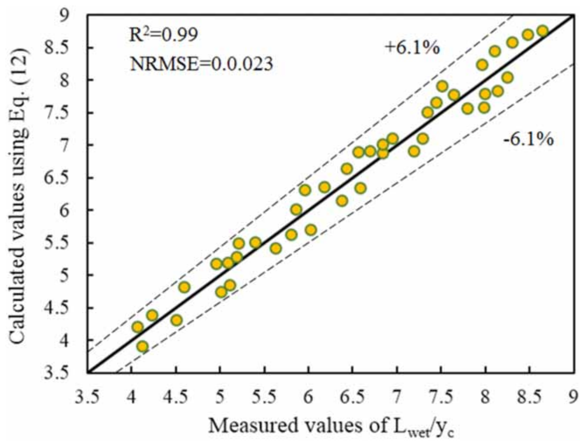


**Figure 7** | Comparison of the measured and calculated values using Equation (12) for the relative wetted length.

values of relative wetted length with a maximum relative error of 6.1%. Figure 7 shows the comparison between the laboratory and calculated values of the relative wetted length.

## Relative pool depth

The falling jets, after impacting with the downstream bed, causes some flow to return to the vertical drop wall and form a pool behind the jet. The depth formed by the back flow near the wall of the vertical drop structure is called the pool depth (see Figure 8).

In Figure 9, the relative depth of the pool at three relative diameters of the screen versus the relative critical depth, is shown. It can be seen that by increasing the relative critical depth, the relative depth of the pool increases in all three relative diameters. Also, the pool's relative depth values of the present research for the relative diameter of 0.067 are in good agreement with

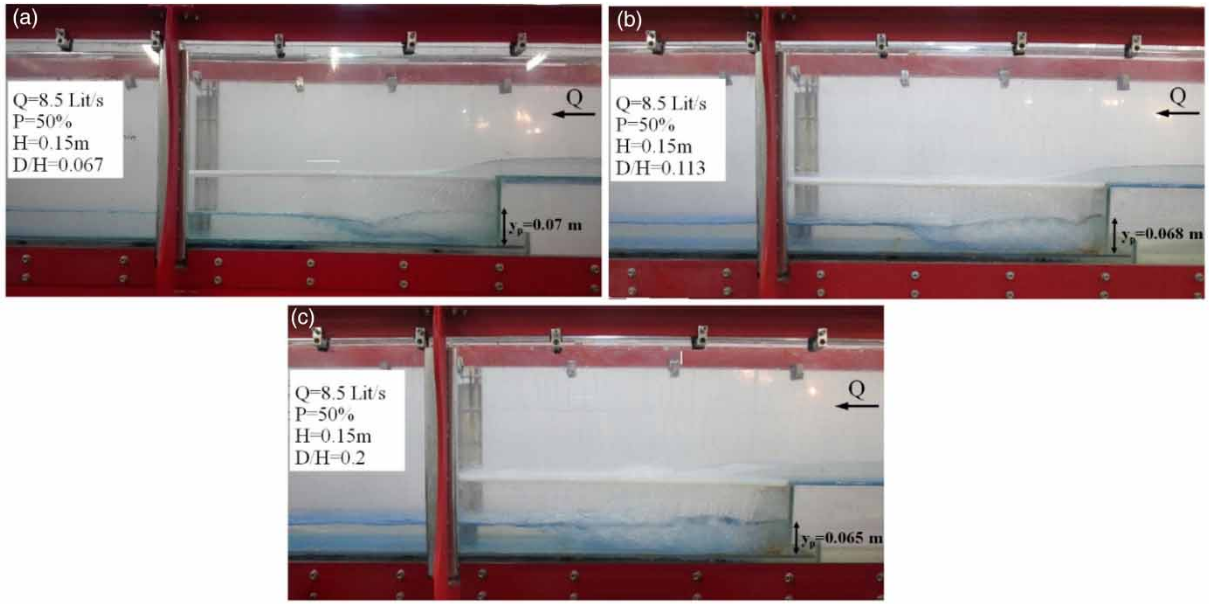


**Figure 8** | The pool depth downstream of the vertical drop equipped with a horizontal screen with Q = 8.5 Lit/s (a) D/H = 0.067 (b) D/H = 0.113 (c) D/H = 0.2.

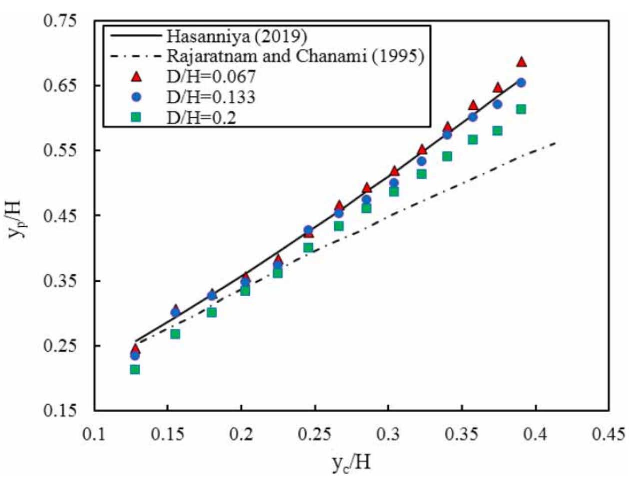


**Figure 9** | Relative pool depth changes versus relative critical.

Hasanniya (2019) studies for the same relative diameter. According to Figure 9, for the vertical drop with a horizontal screen for three relative diameter of the screen, the pool depth is increased compared to the plain vertical drop (reported by Rajaratnam & Chamani 1995). This increase is due to the increase in the angle of the falling jet for the vertical drop equipped with a horizontal screen, compared to the absence of screens. In addition, the application of horizontal screens at the brink of a vertical drop, creates a large number of submerged jumps in the pool that also increase the relative pool depth. It is observed that the relative depth of the pool decreases with increasing the hole diameter of the horizontal screen. By increasing the diameter of the screen, the angle of jet from the screen is reduced and the relative pool depth is decreased.

Compared to the horizontal screen with a relative diameter of 0.067, the use of screen with a relative diameter of 0.2 has reduced the relative depth of the pool by 8.5%.

Regarding the laboratory data, Equation (13) was used to estimate the relative depth of the pool with three relative screen diameters of the present study.

$$\frac{y_p}{H} = 1.265\left(\frac{y_c}{H}\right)^{0.885} + \left(\frac{D}{H}\right)^{-0.064} \tag{13}$$

Equation (13) leads to a determination coefficient ($R^2$) and normalized root mean square error (NRMSE) of 0.98 and 0.037, respectively. This equation estimates laboratory values of relative depth of the pool with a maximum relative error of 5.4%. Figure 10 shows the comparison between the laboratory and calculated values of the relative depth of the pool.

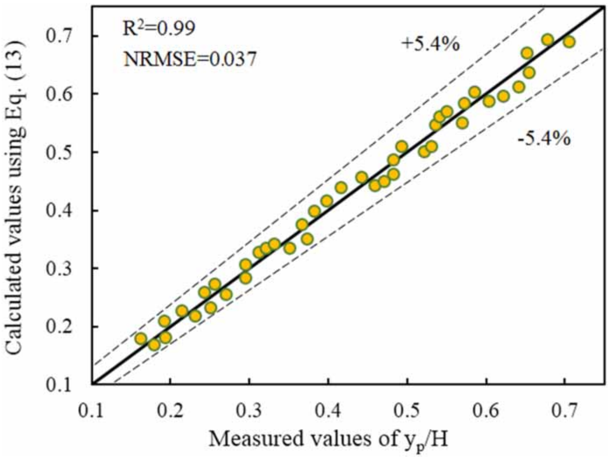


**Figure 10** | Comparison of the measured and calculated values using Equation (13) for the relative depth of the pool.

## Relative length of drop (mixing length)

Passing strip jets through the horizontal screen, causing numerous jumps in the pool, creates a uniform depth downstream of the drop. The longitudinal distance from the brink of the drop to the section where downstream depth of the flow becomes uniform and the air bubbles entering the flow are not visible, is called the 'mixing length' (see Figure 11).

Figure 12 illustrates the variations in the mixing length of the drop versus the relative critical depth for three relative diameters of the holes of the screen. It is seen that as the relative critical depth increases, the mixing length of the drop for three relative diameters increases. Also, the mixing length values of the present research in the relative diameter of 0.067 are in good agreement with the results of the Hasanniya (2019) studies in the same relative diameter. Increasing the relative diameter of the screen, the mixing length also increases. The reason for this is the

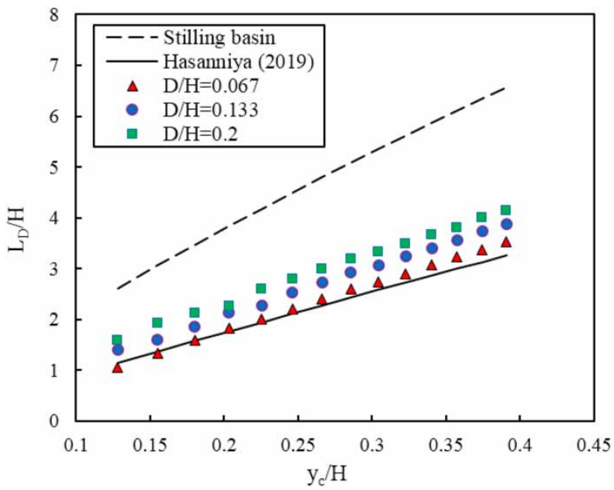


**Figure 12** | The relative drop length versus relative critical depth.

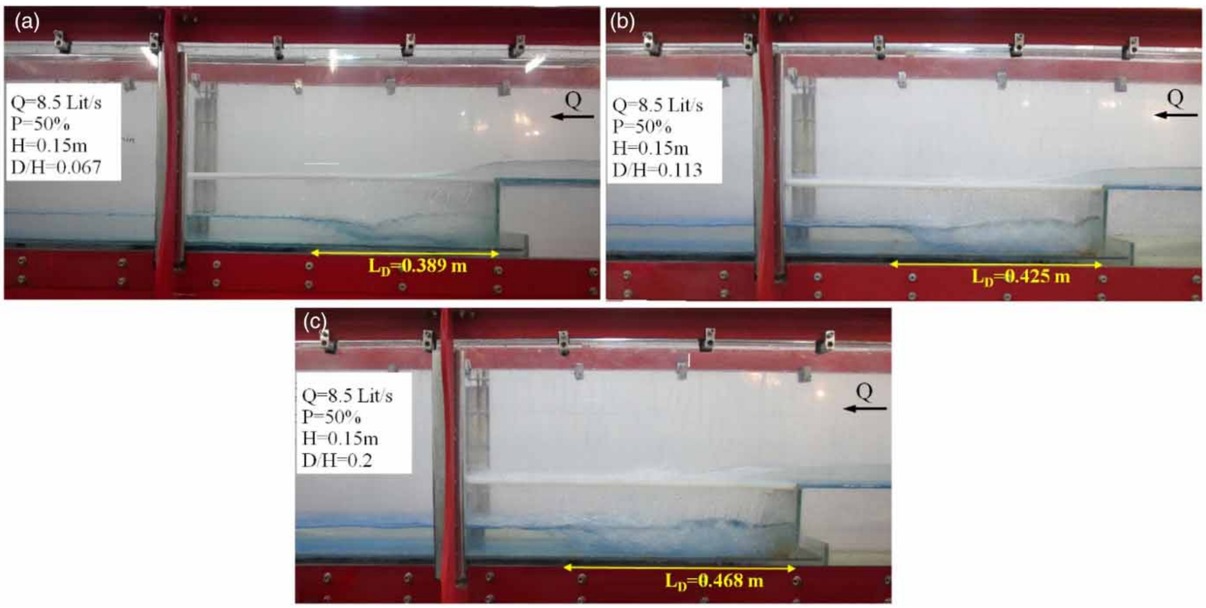


**Figure 11** | The mixing length from flow passes through the vertical drop equipped with a horizontal screen with Q = 8.5 Lit/s (a) D/H = 0.067 (b) D/H = 0.113 (c) D/H = 0.2.

increase in air entrainment due the collision of falling jets with high diameter hole of screen. Since the air bubbles created by the air entrainment tend to move along with the flow, therefore, the movement of these bubbles to downstream causes an increase in the mixing length.

According to Figure 12, it is observed that the utilization of screens significantly reduces the drop length compared to the utilization of a type 1 stilling basin. Also, the vertical drop length gradient with horizontal screens of the present study is also lower compared to the vertical drop with a type 1 stilling basin. This means that the greatest decrease in the length of the vertical drop occurs in the higher critical depth compared to using a stilling basin. Screens with relative diameters of 0.2 and 0.133 increase the mixing length by 15 and 27%, respectively, compared to screen with relative diameters of 0.067.

Equation (14) was used to estimate the mixing length with three relative diameters of screen in the present study.

$$\frac{L_D}{H} = 13.7\left(\frac{y_c}{H}\right)^{0.93}\left(\frac{D}{H}\right)^{0.188} \quad (14)$$

Equation (14) leads to a determination coefficient ($R^2$) and normalized root mean square error (NRMSE) of 0.96 and 0.023, respectively. This equation estimates laboratory values of relative depth of the pool with a maximum relative error of 5.7%. Figure 13 shows the comparison between the laboratory and calculated values of the mixing length.

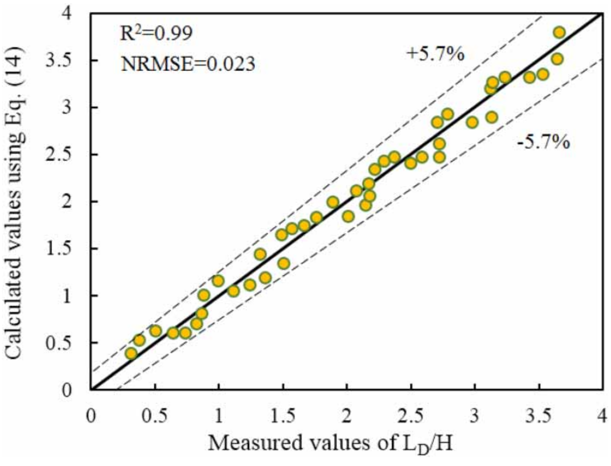


**Figure 13** | Comparison of the measured and calculated values using Equation (14) for the relative drop length.

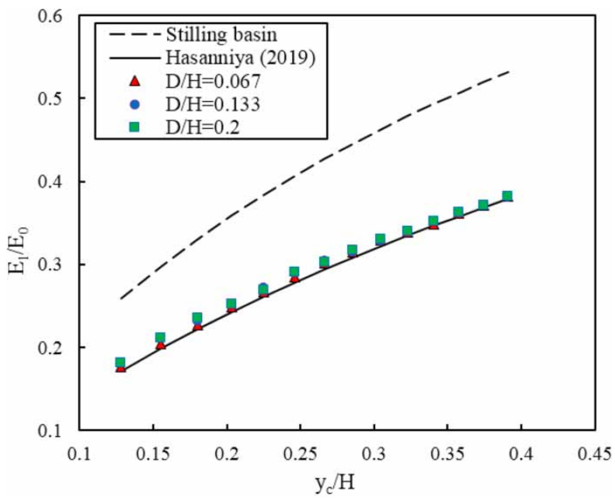


**Figure 14** | Normalized residual energy changes versus relative critical depth.

## Normalized residual energy

The normalized residual energy is equal to the difference between downstream and upstream energy. Figure 14 shows the normalized residual energy values for three relative diameters of screen. It is observed that the normalized residual energy increases with relative critical depth. The normalized residual energy values of the present study are in close and appropriate agreement with the results of Hasanniya (2019) studies. It is seen that the relative diameter of the screen has very little effect on normalized residual energy of the vertical drop equipped with a horizontal screens. Also, the increase in air entrainment due the collision of falling jets created in the horizontal screens, has reduced the normalized residual energy, compared to the stilling basin (in all three relative diameters of the screen by 31% on average).

## DISCUSSION

In the present study, the hydraulic parameters of the vertical drop equipped with a horizontal screen were investigated by considering three different relative diameters of holes. The experiments were performed using a constant screen porosity and a relative critical depth ranging from 0.13 to 0.39. The parameters of relative wetted length, relative pool depth, mixing length and normalized residual energy were investigated. The following results can be drawn:

- By increasing the diameter of the screen holes, the wetted length of the screens increases. Screen with a relative diameters of 0.2 increases the wetted length by 18.5% compared to the screen with a relative diameters of 0.067.
- The depth of the pool decreases with increasing the relative diameter of the screen. Screen with a relative diameter of 0.2 has the lowest values of the depth of the pool.
- The relative diameter of the screen is inversely related to the mixing length and the use of these screens reduces the mixing length by more than 38%.
- The relative diameter of the screen has no effect on the Normalized residual energy of the vertical drop, however, using the vertical drop equipped with a horizontal screen reduces the residual relative energy by 30% compared to the stilling basin.
- If it is possible to prevent the obstruction of the openings of the horizontal screens against the debris flow with appropriate solutions, according to the results, it can be considered as an alternative to stilling basin in downstream of the vertical drop.

## CONCLUSION

The range of the Froude number downstream of the vertical slope in present study is between 3.9 and 5.3. A type 1 stilling basin is commonly used to dissipate energy downstream of the vertical drop (Rand 1955). In the design of stilling basins, usually an attempt is made to make the hydraulic jump inside the basin, and this requires to take in account the tailwater depth. Sometimes, to form the hydraulic jump inside the stilling basin, the end sill or a change in the pond bed level are used. However, the horizontal screen at the vertical drop do not require the tailwater depth to reduce the normalized residual energy or to form the hydraulic jump, and reduce the normalized residual energy further than the stilling basin. On the other hand, due to the decrease in the relative energy of the horizontal screen compared to the stilling basin, it is obvious that these screens have a lower relative tailwater depth. Therefore, the use of horizontal screens at the vertical drop compared to stilling basin has the following advantages:

- No need for the tailwater depth or considering arrangements for hydraulic jump inside the stilling basin.
- Reduction of the size of the stilling basin required for energy dissipation due to decrease of the mixed length.
- Decrease of the normalized residual energy or increase of flow energy dissipation.

However, due to their emergence, these screens have not been implemented in practical projects so far, and if they are implemented, they also have disadvantages. Flow containing suspended sediment and debris flow in channel and irrigation networks are one of the serious problems that can affect its hydraulic performance by blocking the openings of the screen. The size of the diameter of these screens can be effective in preventing them from clogging the hole and this requires further investigation. According to the results, considering all the hydraulic conditions and considering the advantages and disadvantages of the horizontal screen as energy dissipater structure, these screens can be mentioned as an alternative to the stilling basin in the downstream of vertical drop, provided that check its obstruction against the debris flow.

## DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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First received 29 October 2020; accepted in revised form 10 March 2021. Available online 22 March 2021