Advanced Engineering Letters Vol.1, No.3, 71-79 (2022) e-ISSN: 2812-9709

THE EFFECT OF SCREEN WALL ON FLOW ENERGY DISSIPATION: A REVIEW

UDC:532.559.8
Review https://doi.org/10.46793/adeletters.2022.1.3.1

Arwa A. Mala Obaida[1], Noor I. Khatab[1], Ahmed Y. Mohammed[1*]

[1]University of Mosul, College of Engineering, Dams and Water Resources Engineering, Iraq

Abstract:
Several studies indicate that using hydraulic structure results in some adverse effects that affect the stability of these structures, including scouring the floor. Many researchers resorted to using defensive means to reduce the flow's speed and energy as much as possible. One of these means is the use of screen walls. Therefore, the current study focused on reviewing different types of research that dealt with the help of screen walls by changing the location of the screen and geometric shape, such as the diameter of the holes, thickness of the screen wall, porosity, changing the geometric arrangement of the gaps such as the square, triangle and hexagon, as well as the use of a screen inclined at a certain angle, use of triangular meshes and use Artificial intelligence programs to simulate and compare results.

ARTICLE HISTORY
Received: 05.05.2022.
Accepted: 29.08.2022.
Available: 30.09.2022.

KEYWORDS
Screen walls, energy dissipation, Froude number, porosity, hydraulic jump, scour

1. INTRODUCTION

Hydraulic structures are one of the essential means of water storage and control. One of these necessary facilities has many uses in water engineering, such as flow regulation, measuring discharge, or raising the water level. The weirs of different types and shapes are arranged by the state of the Extrusion section, edge nature, edge straightening, or edge shrinkage [1].

Hydraulic structures are exposed to water waves with sizeable kinetic energy due to the high flow velocity. Which causes scour at the bed and banks of the canal downstream of these structures. The importance of this phenomenon has intensified efforts by engineers in water resources engineering to use means that dissipate the high flow energy so that it does not harm those facilities. Among those methods, porous baffle or (screen walls) were used as a convenient option to dissipate the flow energy instead of the classic hydraulic jump. This study aims to review several studies that dealt with screen walls as an energy dissipation in hydraulic structures and compare their use style.

2. SCREEN WALLS

They are porous vertical baffles used to disperse flow energy downstream of tiny hydraulic structures located within a short distance of the flow domain to reduce the scour that results from the high flow speed. The benefit of these walls is increased when the bed materials are soft because they are more affected by scouring [2]. They are of different shapes, such as circular, square, hexagonal, and other diameters. They are also set at various levels from the wall. Recent experimental research has shown that dissipate than a hydraulic leap created in typical stilling basins. The laboratory tests use the screen placement relative to the hydraulic structure, the height of the upstream flow, the thickness of the screens, and the Froude number of the upstream flow as significant factors.

*CONTACT: Ahmed Y. Mohammed, e-mail: a.altaee@uomosul.edu.iq

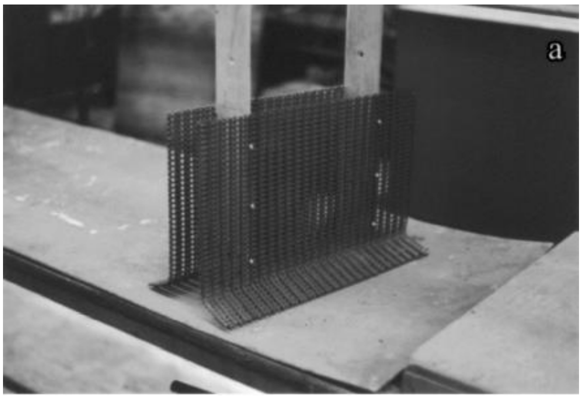
3. ENERGY DISSIPATION TYPES

Dams, blasts, weirs, and other water-powered structures are utilized for various purposes, including irrigation, flood control, and electric power generation. Since the velocity of the stream downstream of these structures is high and supercritical, that may lead to scouring of the bed and sides of canals and rivers. Therefore, researchers and engineers in hydraulics devoted their efforts to using hydraulic structures that reduce and dissipate the kinetic intensity of the flow downstream of the facilities and make the flow velocity subcritical by making a hydraulic jump despite the various means of dissipating energy of the stream, such as the stilling basins, roller buckets, free jets, and hydraulic jumps [3]. In recent years, an alternate way for dissipating surplus energy in water downstream of minor hydraulic structures has been devised, namely using screens.

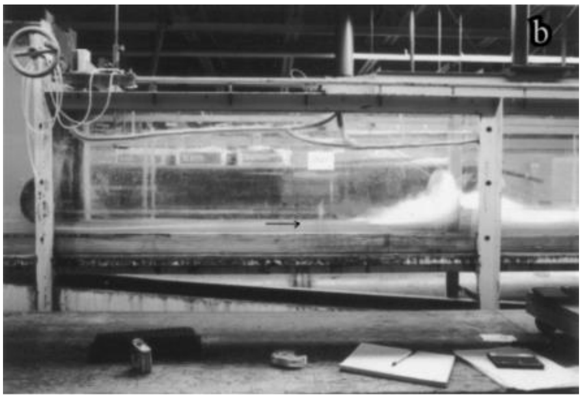
4. APPLICATIONS STUDIES

In the study [4], the hydraulic performance of the double screen was analyzed. The study included the impact of porosity and distances between the screen walls on the transition coefficient and the dynamic pressure change next to the screen walls. Research has shown that vertical screen walls are used to break waves in deep water, reduce the waves' energy, and dissipate the turbulence inside the wave's hole. The dynamic pressure next to the screen walls decreases with an expansion in the distance between the single and double screen walls: the transmission coefficient and the length depend on the field and financial requirements.

A progression of research centre trials was conducted on a horizontal rectangular channel with 0.45 m width, 0.43 m depth, and 6.3 m length [5]. The results showed that the porosity of 40% is considered the best percentage in reducing the flow of energy with double and single walls and that the percentage of energy dispersal is more significant than that produced by the traditional jump. And it will be a substantial jump in case leaving screen walls. The results also showed that the flow in the shortfall of screen walls is a supercritical flow and a Froude number Fr_1 is approximately equal to 1.65. The tailwater depth is 0.28 times the depth of subcritical flow Y_2 at the same Froude number in the traditional jump and generates a secondary leap behind the screen walls; the tailwater depth should be about one-half the depth of the first jump (Y_2) Fig. 1.



a)



b)

Fig. 1. a) Double Screen Configuration; b) Hydraulic Forced Jump at Screens [5]

In research [6] adopted a theoretical model to foresee the pressure-driven execution of the efficiency of the screen walls 1 mm. A link was given in the research to calculate the release through the screen walls, which was a function of Froude number, specific energy, Reynolds number and Weber number. He also concluded that hydraulic friction does not affect the flow from the surface of the screen walls. The model was used to predict the length of the wetted perimeter of the screen walls to correspond to the given discharge.

A laboratory analysis to dissipate the flow energy using screen walls it was reported in the research [7]. The experiment's variable factors were the wall's porosity, thickness, and area. The limits of the Froude number (Fr) were between 5-18, and the porosity (ρ_o) was between 20-60 %. As for the presentation of the walls, the screen and its efficiency decreased with an expansion in the distance from the wall to the gate to the depth of the opening at the bottom of the gate X/d. The results showed that the porosity of 40% is considered the optimum range in dissipation flow energy. Research [7] has shown that double screen walls dissipate flow energy more than single screen walls.

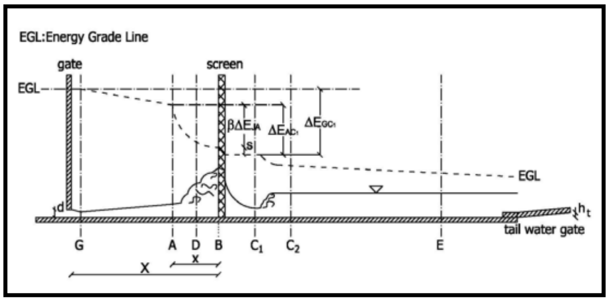
In research [8] tests were conducted to find the effect of inclined screen walls on energy dissipation. Screen walls with holes, each with a 1 cm diameter and a porosity of 40%, were used. The research included the angle of inclination, wall thickness, wall location at 100 times from the water depth at the gate upstream of flow, and Froude number ranging from 5-24. Results are shown that the tilted screen walls scatter more energy than the vertical screen walls.

In research [9] conducted a laboratory analysis to dissipate energy downstream of small hydraulic structures using double triangular inclination screen walls at 60°- the porosity of the screen was 40%. The main parameters in the current analysis were depth of the water upstream of the screen, location of the screen, the Froude number upstream the screen ranging between 7.5-25.5 and depth of the gate opening 1, 1.25, 1.6, 1.7, 2, 2.5, 2.7, 3.2 and 3.3 cm. The study's results showed the use of a triangular screen with the same percentage of porosity. Its effect is little in dissipating the flow energy compared to the screen that is placed vertically.

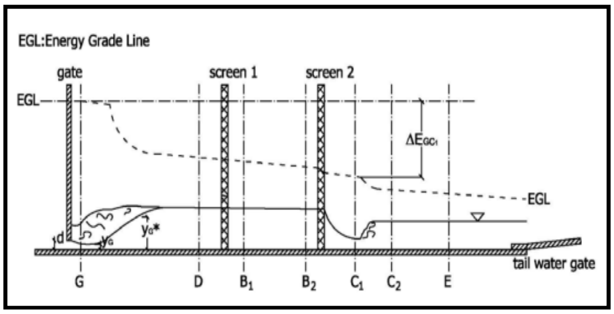
A laboratory analysis to find the effect of vertical and inclined triangular screen walls below small hydraulic structures on energy dissipation was presented in research [10]. The significant variables were determined, such as the location of the screen from the hydraulic design, depth of flow, thickness of the screen wall and the Froude number that was measured upstream of the flow. The values of the Froude number ranged from 7.5 to 25.5. The results of the analysis showed that the vertical and inclined triangular screen walls reduce the flow energy significantly compared to the classical hydraulic jump for the same Froude number values.

In research [11] conducted a laboratory analysis to show the effect of tailwater depth and the effect of using double screen walls with one arrangement and two arrangements in reducing the Energy Fig.2

The porosity of 40% was used, and the values of Froude's number ranged from 5 to 22.5. Two heights of the gate were used, 2 and 3 cm. The results of the experiments for the same Froude number showed that the flow energy decreased when using the screen walls compared to the classical hydraulic jump. Also, the results showed that using two double screen walls better dissipates energy flow compared to using a single arrangement of dual screen walls.



a)



b)

Fig. 2. a) General sketch to increase energy loss of one double arrangement screen, b) General illustration to increase energy loss of tow arrangement dual screen [11]

In the research [12,13], the energy dispersion of the flow downstream of small water-powered facilities was analyzed using a horizontal rectangular laboratory channel with a length of 7.5 m, width and depth of 29 cm and 70 cm, respectively. A Sluice gate was placed under which the water flows toward a screen wall placed perpendicular to the direction of the flow Fig. 2. which is utilized as an elective apparatus to dissipate the kinetic energy of the stream. The significant variables adopted in the experiments are porosity, the thickness of the screen wall, the location screen wall, and the Froude number (Fr), measured upstream of hydraulic structures. The supercritical flow was adopted, as the obtained Froude values (Fr) ranged between 5-18, the porosity value ranged between 20-60 %, and the screen wall was fixed at a distance of 100 times from the depth of the water. This analysis reached the screen's performance in dissipating the flow energy according to the amount of Froude number, as the jump becomes stable when Froude comes to the value of 4.5-9 [3]. And the energy deficiency in the case of using the screen wall and at Fr equal 12 is more significant than the classic hydraulic jump. The experiments have proven that the porosity value of 40 % gives the best value for the flow energy dissipation. Double screen walls provide the most significant dissipation in the flow energy contrasted with the case of using a single screen wall Fig. 3 and 4.

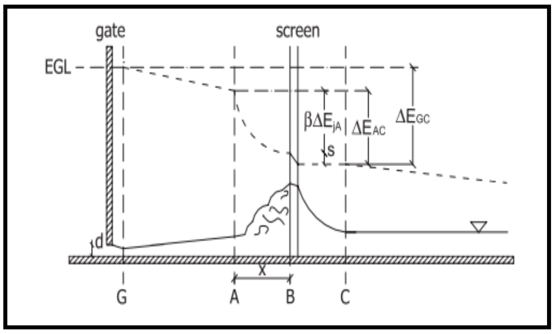


Fig. 3. Illustrates the flow pattern and energy loss [12,13]

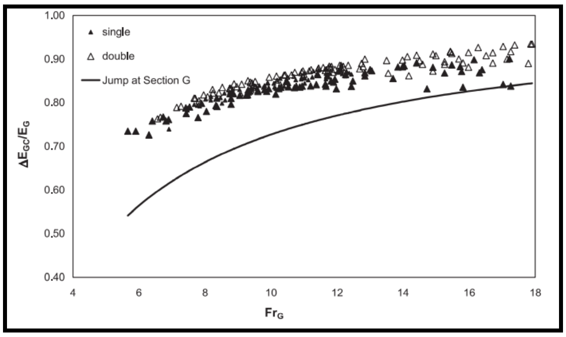


Fig. 4. Compatibility of single and double screens at optimal porosity [12,13]

In research [14] was analyzed the effect of tailwater on the dissipation of flow energy using single and double screen walls. The results of the analysis showed that tailwater had no impact on the excess flow energy, and the outcomes likewise showed that double screen walls dissipate the flow energy more than single screen walls.

A laboratory analysis in a channel with a length of 5 m, a width of 30 cm, and a depth of 45 cm was presented in research [15]. A Sluice gate was used to obtain a supercritical flow. Screen walls have been used to dissipate flow energy, with three diameters of 0.8, 1.2, 1.6 cm and three thicknesses of 0.8, 1.2, and 1.6 cm with 40% porosity. The results proved that there is an optimum diameter for the openings of the screen wall, as (1.2) cm gives greater efficiency than other diameters. The effect of this diameter appears clearly when the distance from the wall to the gate to the depth of the opening at the bottom of the gate X/d equals 40. In contrast, the effect of this diameter decreases relatively with an increase of (X/d) from 73. 33 to 120.

In research [16] was presented the scour downstream of screen walls were used to reduce flow energy, the impact of diameter openings of the screen walls dc, their thickness, and their distance from the gate on the scour process, as well as the scour in open channels without the use of screen walls. There were 140 trials done, 120 with screen walls and 20 without the screen. The testing was placed in a concrete channel that measured 24.65 meters in length, 0.81 meters in width, and 0.76 meters in depth. The floor was scattered with crushed stone as mono size, with two different heights for the entrance under the gate, three different diameters for the screen wall apertures, two wall thicknesses, and five discharges (Fig. 5). The findings indicate that the optimal diameter of hole screen walls for minimizing scouring depth is 1.2 cm, as opposed to other diameters, which is particularly evident when the screen wall thickness is 0.8 cm. this is shown by dimensional analysis of the elements impacting the dimensions of scour hole downstream screen walls, as well as by examining the laboratory data, which have a coefficient of determination R^2 equal to 0.907.

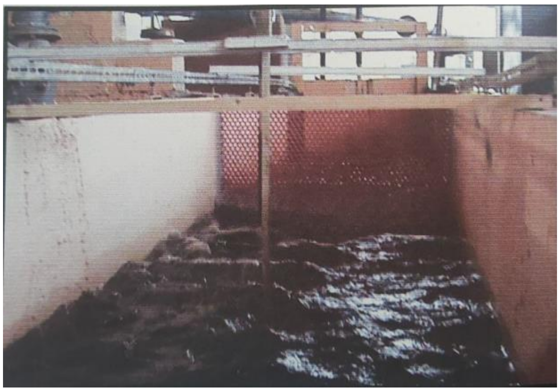


Fig. 5. Ground during operation of the experiment [16]

In research [17] was presented a laboratory analysis of the dissipation of flow energy downstream small hydraulic facilities using screen walls containing different shapes to know the practical formation of the holes on the productivity of dissipation energy flow. Experiments were carried out using an artificial channel and three spots in the screen wall: hexagonal, rounded square-shaped. Each model was constructed using a different dimension, with a fixed porosity of 40 %. The slots were placed at a distance of 120,80 times from the gate slots for each model. The researchers [17] concluded that the flow's kinetic energy decreases during the passage of water through the openings of the screen walls. The power of the stream decreases using screen walls of different shapes compared to the traditional weirs that do not contain slots Fig. 6. Additionally, increasing the length of the hexagonal aperture in the screen walls reduces wasted energy.

Fig. 6. Laboratory channel during operation using screen walls [17]

In research [18] was presented a laboratory analysis on the scour downstream the dams using screen walls and its comparison with the height of the sifting in the case of not using the screen walls. Use two measurements of weir 25,30 cm and different diameters of the screen wall openings 0.8,1.2,1.6 cm and two instances of walls (single and dual) and used five discharges and two types of crushed gravel with an average diameter of 0.79,1.59 cm. The results found that the bilateral walls with a diameter of 1.59 cm and a weir depth of 25 cm gave the lowest scour depth compared with the rest of the diameters and single screen walls without screen walls. As for the bed material, the results showed that the crushed stone model of 1.59 cm gives a cut depth and length less than the model of 0.79 cm.

The effect of screen walls on the dissipation of flow energy was studied in research [19]. The porosity ranged from 40 % to 50 %, and the values of the Froude number were between (2.5 – 8.5). The single and double screen walls used openings ranging from 1 to 5 cm. The researcher concluded that screen walls significantly dissipate the flow energy compared to traditional hydraulic jumps. And double screen walls dissipate energy to flow more than single-screen walls. Also, the results showed that the double screen walls with a porosity of 40% and Froude number significantly reduced the flow energy. The effect of arranging the holes in the double walls was small in reducing flow energy.

In research [20] was presented a laboratory analysis to impact using single and double screen walls to reduce hydraulic jump properties of supercritical flow for soft soils, with two types of porosity 50 and 60 %. Different angles of the screen walls ranged between (45^o 90^o and 135^{o,} And the values of the Froude number Fr ranged between 1.5-6. The depth of water after the sieve wall is 0.79 times y_2. The results of the analysis showed that the porosity value of 40% gives the best value for the flow energy dissipation. The use of double screen walls provides the most considerable dissipation of flow energy relative to the case of using a single screen wall. The results of researchers [13,14,19] match that the screen walls act as energy dissipators on reverse-bed stilling basins).

In research [21] studied reducing scour in open channels by using screen walls that create a hydraulic jump upstream screen wall to reduce the energy of the supercritical flow. Porosity was used (50) %, Froude number ranged between 4.5-10.6, and single and double screen walls were used. Two reverse slopes were used Fig. 7. The openings of the screen walls were square, taking into account the location and angle of the wall from the edge of the jump. The results of the analysis showed that the reverse slope with 0.025 reduces the dimensions of the scour hole more than the slope with a value of 0.015. Double screen walls eased scour more than single walls. And that the distance of the wall from the jump doesn't influence the decrease of the stream's energy.

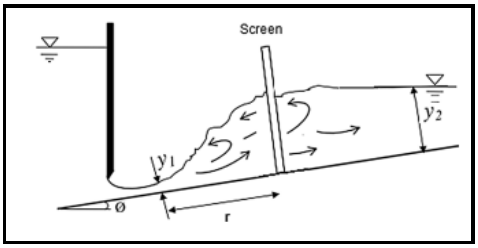


Fig. 7. Single screen hydraulic jump on reverse bed slope [21]

Energy dissipation using a horizontal double screen with vertical drops is presented in research [22]. The experiments included using two types of porosity, two depths for the vertical projection, and three distances between the screens. Froude's number values ranged between 0.077 to 0.224, with different values for critical depth. The results of the experiments showed that changing the distances between the screens has little effect on the dissipation of energy and required depth. On the other hand, it was found that using a horizontal double screen reduces the flow energy more than using a single screen. And the dual screen converts the flow from supercritical to subcritical. Also, the length of the vertical drop reduces the flow energy and critical depth.

A laboratory analysis investigating flow energy dissipation movable bed downstream of a screen is presented in research [23]. The experiments were conducted using two percentages of porosity, 40% and 50%, by using single and double screens and three different sizes of bed materials; the values of the supercritical Froude number ranged from 5-18. the results showed that The dual screen with a porosity of 40% could dissipate the flow energy significantly. Using a single screen with a porosity of 50% causes the least scour of the bed material for a constant amount of dissipated energy.

In research [24] laboratory and theoretical analysis were carried out in order to reduce the energy dissipation of supercritical flow by means of a model. Sudden contractions were used with three sizes, 5 cm, 10 cm and 15 cm, the relative contraction ranged from 8.9 to 9.7. The values of the Froude number upstream of the sudden contraction ranged between 2 to 7. the energy dissipation increases with the increase of the Froude value. Also, the relative energy dissipation of 15 cm contraction is more than 10 cm.

A laboratory analysis was conducted to reduce the energy flow using a vertical drop with horizontal screen walls, it was reported in the research [25]. Three heights of the steep drop were used, with two ratios of porosity, 40% and 50%. The results showed that the vertical drop equipped with a screen is suitable for dissipating the flow energy because it has a higher depth towards the river course than the horizontal drop. The Froude number was reduced from 3.7–6.1 to 0.67–1. It was also noted that the use of porosity of 40% reduces the flow energy by 8.5% % compared to the porosity of 50%. However, the porosity has little effect on the relative depth, the ratio of the depth of the pool and the dissipation of the flow energy. The results showed that the increase in the critical depth and the pool depth ratio increases the dissipated power.

A laboratory analysis for flow energy to dissipate flow energy using a vertical screen upward of an inclined drop is presented in research [26]. The experiments were carried out using two types of porosity, 40% and 50 %, two depths of 0.15,0.25 m and three angles of 26.56, 33.7, and 45 degrees of the watershed. The results showed that the Froude numbers decreased from the range of 4.49–7.72 to that of 1.66–2.11. as the depth of both inclined and plain drop increases, the depth of the water downstream of the screen wall increases, and consequently, the dissipation of the flow energy for both pores and three angles decrease. By using a screen with 40% porosity downstream of an inclined drop, the downstream relative depth increased 121.87%, 114.78%, and 105.27% for the angles of 26.56, 33.7, and 45 degrees, respectively. Also, using a screen with 50% porosity in conjunction with an inclined drop increased the downstream relative height by 130.26%, 123.58%, and 117.73%, respectively, for used angles.

SVM performance for predicting the effect of horizontal screen diameters on the hydraulic parameters of a vertical drop is presented in research [27]. One hundred sixty-four experimental conducted, and the models' correctness was evaluated using three statistical metrics, namely RMSE, R^2, and KGE. The ratio energy dissipation $\Delta E/E_0$ and the relative pool depth yp/H were input as dimensionless parameters into the numerical simulation. The findings indicate a strong connection between the SVM-derived values of ΔE/E0 and yp/H and the experimental values. The screen's relative diameter D/H and crucial relative depth yc/H were the strongest predictors of hydraulic performance.

The effect of varying screen widths on the properties of submerged hydraulic jumps was studied in research [28] in a 0.30-meter-wide, 0.468-meter-deep, and 15.6-meter-long channel. The effect of passing flow over changing screen area on the hydraulic jump performance was investigated using screens with a 22 cm width and a 3 cm depth. The screens contained 24 holes with diameters of 0.4, 0.6, 0.8, 1.00, and 1.2cm and corresponding relative hole areas of 0.046, 0.103, 0.183, 0.285, and 0.411m^2 respectively. The findings indicated that screens of varying relative widths enhanced the submerged hydraulic jump's properties. The optimal relative width of the screen that maximized relative energy loss while minimizing the depth and duration of the submerged hydraulic leap was around 1. When a correction actor was utilized, there was satisfactory agreement. The theoretical equation for the relative energy loss calculated from the experimental data reasonably agrees with the experimental findings.

In research [29] laboratory analysis was using the screen as a triangle V-shape with different angles, blockage ratios and circular bars to improve the performance of traditional screen walls that are exposed to problems of blockage opening and cause economic and environmental issues. The analysis also included the use of blockage ratios and expenses that are tested using a physical model. The analysis results showed that the head loss coefficient is reduced by using a triangular screen at an angle of 90 degrees and circular bars compared to a traditional screen. The head loss coefficient decreases when using a low-angle screen. The head loss coefficient of screen walls increases rapidly with the blockage ratio and flow discharge.

In research [30] laboratory analysis was using to reduce the flow energy using a vertical drop and a vertical screen wall, as ratios do the wall expansion from 0.5 to 1, two porosities were used 40%, 50%, values of Froude number ranged from 0.86 to 0.92. the results show the wall expansion increases energy dissipation by 25%, 44% and 48%, and decreases the basin's depth. The effect of the porosity ratio on the excess flow energy is small, and its impact is limited to reducing the depth of the bay and increasing the depth downstream of the basin. And under the same hydraulic conditions with increasing the height of the drop, the dissipated energy relative to the measurement of the impact intensity of the water passing over the fall Towards the downstream drop floor increases, while the depth of the water decreases in the basin. When the discharge increases at a porosity of 40%, a submerged hydraulic jump is formed that moves upstream screen; on the other hand, using the porosity of 50% leads to the formation of a free jump that moves downstream.

5. CONCLUSIONS

Flow kinetic energy should be reduced by reducing velocity flow and converting the flow from supercritical to subcritical flow. These investigations have proven to be an excellent tool to dissipate energy and regulate the supercritical flow from than classical hydraulic jump. So, this study confirmed that:

Froude number at a value of 12 gives the most significant increase in energy dissipation; the diameter of 1.2 mm is the best value to dissipate energy than other diameters. The effect of the porosity ratio on the excess flow energy is small, and its impact is limited to reducing the depth of the basin and increasing the depth downstream of the bay.

Using the screen as a triangle V-shape with different angles, blockage ratios and circular bars. Reduced The head loss coefficient by using a triangular screen at an angle of 90 degrees and circular bars compared to a traditional screen.

The optimal relative width of the screen that affects to maximizes close energy loss while minimizing the depth and duration of the submerged hydraulic leap was around 1.

Using vertical drop with horizontal screen walls. It is suitable for dissipating the flow energy because it has a higher depth towards the river course than the horizontal drop and by using vertical drop.

Use model that sudden contractions with three sizes 5 cm, 10 cm and 15 cm were used, the relative energy dissipation of 15 cm contraction is more than 10 cm. energy dissipation increases with increase Froude number.

For a movable bed downstream of a screen using two percentages of porosity, 40% and 50%, The double screen with a porosity of 40% can dissipate the flow energy significantly more than a single screen with 50% porosity.

Two horizontal double screens with two depths of vertical drops, two types of porosity and three distances between the screens, and different values for critical depth. Changing the distances between the screens has little effect on energy dissipation and required depth. On the other hand, it was found that using a horizontal double screen reduces the flow energy more than using a single screen. And the dual screen converts the flow from supercritical to subcritical. Also, the length of the vertical drop reduces the flow energy and critical depth.

The double-screen walls with a porosity of 40% and Froude number had a significant effect on reducing the flow energy more than single-screen barriers. The effectiveness of arranging the holes in the double walls slightly reduced flow energy. The tailwater did not affect the dissipation of flow energy.

ABBREVIATIONS

Fr_1- Froude number before the jump
Fr - Froude number, which is measured upstream of hydraulic structures
Fr_G - Froude Number at Section G
Y_2 - Subcritical free jump depth with Froude
X - the distance from the wall to the gate
$\Delta E/Eo$ - relative energy dissipation
(yp/H) - relative pool depth
d - height of the opening at the bottom of the gate
ρ_o - porosity
EGL - Energy grid Line
ΔEAC - Energy Consumption between Sections A and C
ΔEGC - Loss of Energy between sections G and C
EG - energy at section G

D/H - relative diameter
y_c/H - crucial relative depth

REFERENCES

[1] K.N.E. Abd Alkhder, Laboratory Study for Local Scour Downstream of the compound weir, M.Sc. thesis, Department of Dams and Water Resources Engineering. *College of Engineering, University of Mosul*, 2013.

[2] R. Balaji, V. Sundar, Hydraulic performance of double screen breakwaters. *International Conference on Hydro-Science & Engineering (ICHE-2002)*, Warsaw, Poland, 2002: 18-21.

[3] V.T. Chow, Open-Channel Hydraulics, International Edition. *McGraw-Hill Ltd*, 1959.

[4] A.S. Koraim, E.M. Heikal, O.S. Rageh, Hydrodynamic characteristics of double permeable breakwater under regular waves. *Marine Structures,* 24(4), 2011: 503-527. https://doi.org/10.1016/j.marstruc.2011.06.004

[5] N. Rajaratnam, K.I. Hurtig, Screen-type energy dissipator for hydraulic structures. *Journal of Hydraulic Engineering*, 126(4), 2000: 310-312. https://doi.org/10.1061/(ASCE)0733-9429(2000)126:4(310)

[6] T. Wahl, Hydraulic performance of Coanda-effect screens. *Journal of Hydraulic Engineering*, 127(6), 2001: 480-488. https://doi.org/10.1061/(ASCE)0733-9429(2001)127:6(480)

[7] P. Cakir, Experimental investigation of energy dissipation through screens, Master's thesis. *Middle East Technical University*, Ankara, 2003.

[8] G. Balkış, Experimental investigation of energy dissipation through inclined screens, Master's thesis. *Middle East Technical University*, Ankara 2004.

[9] E. Güngör, Experimental investigation of energy dissipation through triangular screens. Master's thesis. *Middle East Technical University*, Ankara, 2005.

[10] Z. Bozkus, E. Gungor, M. Ger, Energy dissipation by triangular screens. *7th International Congress* on *Advances in Civil Engineering* (*ACE 2006*), October 10-13, 2006 Istanbul, Turkey.

[11] V. Aslankara, Experimental investigation of tailwater effect on the energy dissipation through screens, Master's thesis. *Middle East Technical University*, Ankara 2007.

[12] Z. Bozkus, P. Cakir, M. Ger, Y. Ozeren, Energy dissipation through screens, world water and environmental resources congress. *Proceedings of the* 2004 *World Water and Environmental Resources Congress*, June 27-July 1, 2004, Salt Lake City, Utah, pp.1-8.

[13] Z. Bozkus, P. Çakir, A. M. Ger, Energy dissipation by vertically placed screens. *Canadian Journal of Civil Engineering*, 34(4), 2007: 557-564. https://doi.org/10.1139/l06-158

[14] Z. Bozkus, V. Aslankara, Tailwater effect on the energy dissipation through screens. *Proceedings of the* 8th *International Congress on Advances in Civil Engineering*, September 15-17, 2008, Eastern Mediterranean University, Famagusta, North Cyprus

[15] H. A. Mahmoud, Laboratory Study of Energy Dissipation Using Screen Walls, M.Sc. thesis, Department of Civil Engineering. *College of Engineering, University of Dohok*, 2010.

[16] R. Ghufran, Laboratory study of scour downstream screen walls Used as energy dissipaters, M.Sc. thesis, Department of Dams and Water Resources Engineering. *College of Engineering, University of Mosul*, 2011.

[17] Sh. Jalil, A. Yaseen, H. Mahmoud, the performance of screen wall openings shape on energy dissipation. *International Journal of Scientific & Engineering Research*, 4(11), 2013: 1538-1544.

[18] M. Al-Mashhadane, Laboratory study of the effect of screen wall scours using different bed materials, M.Sc. thesis, Department of Dams and Water Resources Engineering. *College of Engineering, University of Mosul*, 2014.

[19] S. Sadeghfam, A.A. Akhtari, R. Daneshfaraz, G. Tayfur, Experimental investigation of screens as energy dissipaters in submerged hydraulic jump. *Turkish Journal of Engineering and Environmental Sciences*, *38*(2), 2015:126-138. https://doi.org/10.3906/muh-1401-15

[20] U.K. Singh, Experimental study on single and double screen type energy dissipator for hydraulic structures, Doctoral dissertation, Civil Engineering Department. *Delhi Technological University,* 2018.

[21] A. Abbaspour, T. Taghavianpour, H. Arvanaghi, Experimental study of the hydraulic jump on the reverse bed with porous screens. *Applied Water Science*, 9(7), 2019: 155. https://doi.org/10.1007/s13201-019-1032-7

[22] R. Daneshfaraz, M. Majedi, S. Ramzi, R. Norouzi and J. Abraham, Experimental investigation of the effect of dual horizontal screens on the hydraulic performance of a vertical drop. *International Journal of Environmental Science and Technology*, 17(5), 2020: 2927-2936. https://doi.org/10.1007/s13762-019-02622-x

[23] R. Daneshfaraz, S. Sadeghfam, A. Tahni, Experimental investigation of the screen as energy dissipators in the movable-bed channel. *Iranian Journal of Science and Technology, Transactions of Civil Engineering*, 44(4), 2020: 1237-1246. https://doi.org/10.1007/s40996-019-00306-7

[24] R. Daneshfaraz, E. Aminvash, R. Esmaeli, S. Sadeghfam, J. Abraham, Experimental and numerical investigation for energy dissipation of supercritical flow in sudden contractions. *Journal of Groundwater Science and Engineering*, 8(4), 2020: 396-406. https://doi.org/10.19637/j.cnki.2305-7068.2020.04.009

[25] R. Daneshfaraz, V. Hasannia, R. Norouzi, P. Sihag, S. Sadeghfam, J. Abraham, Investigating the effect of horizontal screen on hydraulic parameters of vertical drop. *Iranian Journal of Science and Technology, Transactions of Civil Engineering*, *45*(3), 2021: 1909-1917. https://doi.org/10.1007/s40996-020-00572-w

[26] R. Daneshfaraz, A. Mahd. I. Majedi, A. Bazyarb, J. Abraham, R. Norouzi, The laboratory study of energy dissipation in inclined drops equipped with a screen. *Journal of Applied Water Engineering and Research*, 9(3) 2021: 184-193. https://doi.org/10.1080/23249676.2020.1799877

[27] R. Daneshfaraz, E. Aminvash, A. Ghaderi, J. Abraham, M. Bagherzadeh, SVM performance for predicting the effect of horizontal screen diameters on the hydraulic parameters of a vertical drop. *Applied Science*, 11(9), 2021: 4238. https://doi.org/10.3390/app11094238

[28] S. Elaswad, E. Elnikhili, O. Saleh, Effect of different screen widths on the submerged hydraulic jump characteristics. *The Egyptian International Journal of Engineering Sciences and Technology*, 34(1), 2021: 1-10. https://doi.org/10.21608/EIJEST.2021.62466.1047

[29] M. Zayed, A. El Molla, M. Sallah, An experimental investigation of head loss through a triangular V-shaped screen. *Journal of Advanced Research*, 10, 2018: 69-76. https://doi.org/10.1016/j.jare.2017.12.005

[30] B. Nayebzadeh, M.A. Lotfollahi-Yaghin, R. Daneshfaraz, Experimental study of Energy Dissipation at Vertical Drops Equipped to Vertical Screen with Gradually Expanding at the Downstream. *Amirkabir Journal of Civil Engineering*, 52(12), 2021: 3059-3072. https://doi.org/10.22060/CEEJ.2019.16493.6265