Journal of Technology Research (JTR)
Volume 4, Special Issue, (2026), pp 898-906, ISSN 3005-639X
The 7th Conference of Engineering Sciences and Technology
(CEST-2025)

Comprehensive review on Water Energy Dissipation by using Hydraulic Jump

Amad Deen A. Alghwail

Civil Engineering Department, Faculty of Engineering, Elmergib University, Alkhums, Libya,
*Corresponding author email: aalghwail@elmergib.edu.ly.

Received: 07-10-2025 | Accepted: 25-11-2025 | Available online: 09-03-2026 | DOI:10.26629/jtr.2026.**

ABSTRACT

This research paper looks at how energy dissipation is important for hydraulic structures, especially spillways, to reduce local scour and prevent structural failures. It examines traditional and new techniques for energy dissipation by formation of hydraulic jump, focusing on the most used appurtenances in stilling basins. Comprehensive review addresses how gravitational potential energy turns into kinetic energy, which affects shear stress and sediment transport. It details different methodologies for energy dissipation, the role of the Froude number, standardized designs from the U. S. Bureau of Reclamation, Type I, II, III and IV and enhancements such as baffle blocks, end sill and baffled chutes. Experimental results validate these designs to improve hydraulic performance and manage costs effectively.

Keywords: Hydraulic structure, Water Energy Dissipation, Stilling Basin, Hydraulic Jump, Scour prevention

رؤية شاملة لتبديد طاقة المياه باستخدام القفزة الهيدروليكية

عماد الدين عبدالسلام الغويل

قسم الهندسة المدنية، كلية الهندسة، جامعة المرقب، الخمس، ليبيا

ملخـــــــص البحـــــــث

تتناول هذه الورقة البحثية أهمية تبديد الطاقة للمنشآت الهيدروليكية، وخاصةً المفيضات، للحد من التآكل الموضعي ومنع الأعطال الهيكلية. وتتناول التقنيات التقليدية والحديثة لتبديد الطاقة عن طريق تكوين قفزة هيدروليكية، مع التركيز على أكثر الملحقات استخدامًا في أحواض التهدئة. وتتناول الدراسة كيفية تحول طاقة الوضع الجاذبية إلى طاقة حركية، مما يؤثر على إجهاد القص ونقل الرواسب. وتوضح بالتفصيل منهجيات مختلفة لتبديد الطاقة، ودور رقم فرويد، والتصميمات الموحدة من مكتب استصلاح الأراضي الأمريكي، من النوع الأول والثاني والثالث والرابع، بالإضافة إلى التحسينات مثل كتل الحواجز، وعتبات النهاية، والمزالق المزودة بحواجز. وتؤكد النتائج التجريبية صحة هذه التصميمات لتحسين الأداء الهيدروليكي وإدارة التكاليف بفعالية.

الكلمات الدالة: المنشآت الهيدروليكية، تبديد طاقة المياه، أحواض التهدئة، القفزة الهيدروليكية، الحماية من التآكل.

"Articles published in *J Technol Res* are licensed under a Creative Commons Attribution-NonCommercial 4.0 International License."

1. INTRODUCTION

Hydraulic structures such as dam spillways, culverts and outlet works are commonly constructed in streams which are erodible substances such as sand, clay, and silt. A spillway is a means to prevent dams overtopping in severe weather conditions. Flowing a huge amount of water from the reservoir in a short time period, leading to a very high discharge velocity. This typically takes the form of a highly turbulent supercritical flow within the spillway and in the area directly downstream of the spillway. The elevated flow velocity results in an increase in shear stress at the riverbed level, with the stress becoming significantly greater than in scenarios without the structure. Consequently, there is a marked increase in sediment transport downstream of the structure. The channel bed experiences substantial erosion, commonly referred to as local scour, as shown in Figure 1. Repeated scouring can undermine the foundations of the spillway, potentially leading to the failure of the structure itself in the worst scenario [1, 2]. Therefore, it is crucial to prevent such local scouring.

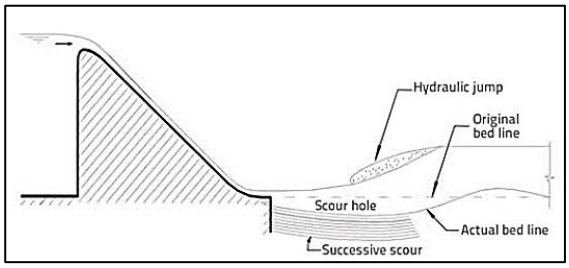

Fig 1. Scour process downstream of a spillway.

This paper provides a detailed comparison of energy dissipation methods, spanning conventional hydraulic jump stilling basins, impact and trajectory structures, and emerging sustainable energy recovery systems.

2. METHODOLOGIES OF ENERGY DISSIPATION

The dissipation of energy in flow over a spillway can occur during the entrance, along the chute, along the trajectory of jet flow in the air, during the plunging of the jet, and within a hydraulic jump [3].

In accordance with Vischer, 1995, there are numerous mechanisms for dissipating flow energy, such as sudden expansions, abrupt deflections, counterflows, rough walls, vortex devices, and spray-inducing devices.

Two fundamental categories of energy dissipaters: hydraulic jump-type and impact-type energy dissipaters. In hydraulic jump-type energy dissipaters, energy is dissipated through the high turbulence of flow at the hydraulic jump. Conversely, in impact-type energy dissipaters, the flow is directed towards obstructions, causing the flow direction to change, which creates turbulence and dissipates flow energy. Impact-type energy dissipaters are generally shorter than hydraulic jump-type dissipaters and are preferred in situations where space is constrained [4].

2.1 Traditional methods

Primarily standardized by the U.S. Bureau of Reclamation (USBR), depend on transforming high-velocity supercritical flow into subcritical flow through the formation of a hydraulic jump. Although these designs are effective, they necessitate substantial concrete civil works and must be meticulously customized according to the flow's dimensionless Froude number (Fr) and the local tailwater conditions. High Fr flows present considerable challenges, particularly the potential for structural failure due to cavitation, which requires strict design constraints on the application of appurtenances such as baffle [5].

2.2 Trajectory methods

Alternative trajectory techniques, such as flip buckets, provide significant initial cost reductions for high-head dams by transferring the dissipation process into the air and the downstream plunge pool. Nevertheless, this

method essentially converts structural risk into geological risk, depending on the stability and monitoring of the natural riverbed [6].

3. THEORETICAL PRINCIPLES OF HYDRAULIC ENERGY MITIGATION

3.1 The Concept of Mechanical Energy of Water

Water flowing over high-head hydraulic structures, such as dam spillways or sluice gates, experiences a significant change in which gravitational potential energy is transformed into kinetic energy. Such transformation leads to water moving at very high velocities (supercritical flow) on the downstream side of the structure [7], it inevitably leads to severe local scouring, which may compromise the toe of the structure, resulting in possible instability and failure of the entire hydraulic system. The primary role of any energy dissipater is thus the methodical decrease of this kinetic energy, mainly by transforming it into heat through turbulent processes.

3.2 Hydraulic Jump and the Fundamentals of Water Energy Dissipation

Hydraulic jump parameters serve as the most frequently utilized method to dissipate the high energy due to the heavy flow from the spillway [8]. It is characterized as a sudden and extremely turbulent transition in open channel flow, where the flow regime changes abruptly from a supercritical to a subcritical state [9]. Energy reduction primarily takes place through significant internal turbulence and shear forces within the characteristic roller of the jump, where kinetic energy is forcefully transformed into thermal energy (heat).

A vital differentiation in the design of hydraulic jumps is the essential dependence on the momentum principle. While energy can be calculated at both the beginning and end of the jump, the energy loss inherent in the jump due to non-conservative turbulence cannot be solely ascertained through the theoretical energy relationship. As a result, hydraulic design fundamentally depends on the pressure-momentum equation to define the relationship between the initial and the requisite sequent depths needed for a stable and contained jump. This engineering methodology transcends basic conservation principles to address the significantly non-uniform pressure distributions and velocity profiles that define the jump phenomenon [10].

3.3 Froude Number (F_r): Design and Scaling of Open Channel Dissipation Structures.

The Froude number (Fr) serves as the main dimensionless parameter that influences the design and scaling of open channel dissipation structures. It is defined as the ratio of inertial force to gravitational force, with the Fr indicating the flow regime: Fr>1 signifies supercritical flow, whereas Fr<1 indicates subcritical flow. The conventional formula for calculating the Froude number in rectangular conduits or channels is given by:

$$\mathrm{F}_r = \mathrm{V}/gD \qquad (1)$$

where (V) is the flow velocity, (g) is the acceleration of gravity, and (D) is the hydraulic depth.

Froude number value is a critical parameter in choosing the suitable design and type of stilling basin, as various ranges dictate the required appurtenances and structural limits. For instance, flows with Froude number ranging from 2.5 to 4.5 often produce problematic downstream waves, whereas Froude number values exceeding 5.8 introduce severe cavitation risk, fundamentally limiting the use of standard baffle-assisted designs [10].

4. STILLING BASINS USING THE HYDRAULIC JUMP (US BUREAU OF RECLAMATION STANDARDIZED DESIGN

Over the past decades, comprehensive experiments have been conducted by researchers. Different types of recommended

stilling basin and apparatuses designs have been proposed [11-20]. Standardization of the USBR's stilling basins resulted from a need for dependable, consistent hydraulic design criteria after a thorough empirical investigation. Having a sufficient tailwater (TW) elevation downstream is essential for any hydraulic jump stilling basin to function properly.

The theoretical sequent depth (D_2) needed to force the jump to form and stabilize inside the basin structure must be met or exceeded by the tailwater. An excessive drop in tailwater, usually 4% below the conjugate depth ($0.96D_2$), can cause the jump to become unstable and possibly sweep out of the basin completely, rendering the structure useless and exposing the channel bed to supercritical velocities.

4.1 USBR Type I Stilling Basin

Type I stilling basin is the basin created by a jump on a horizontal flat floor with no appurtenances. It works with flows that have a Froude number higher than 1.7, enough natural tailwater, and an economically viable jump length (and consequently, basin). In Type I basins, the turbulence of the free hydraulic jump is the only mechanism for energy dissipation. Experimental study conducted by Kamal on types of stilling basins, indicates that type I stilling basin is proper for the low initial velocity less than 5m/sec and Froude number up to 6 [21].

4.2 USBR Type II Stilling Basin

A stilling basin of Type II, which is intended for Froude numbers of 2.5 to 5.0, is frequently utilized for intermediate flow conditions, where the incoming velocity is less than 15 m/s. An end sill, baffle blocks on the floor, and an entrance chute with blocks are the internal appurtenances of the structure. In addition to providing significant energy dissipation through the direct impinging action of the flow, these appurtenances, especially the baffle blocks more significantly reduce the length (L) of the concrete basin needed to contain the jump. This is a significant economic drive because it offsets the cost of building intricate appurtenances [22].

4.3 USBR Type III Stilling Basin

According to US Department of the Interior, bureau of reclamation, Type III has a large factor of safety against jump sweepout and operates equally well for all values of the Froude number above 4.0. Type III should not be used where baffle piers will be exposed to velocities above the 50 to 60 feet per second range without the full realization that cavitation and resulting damage may occur. For velocities above 50 feet per second.

Multiple studies revealed that the efficiency of water energy dissipation is significantly influenced by the downstream water depth. Studies indicate that the minimum water depth for USBR type III is 0.8 times the conjugation depth (y_2). When the depth is less than the minimum weir, jumping outside the stilling basin reduce the effectiveness of dissipation [23, 24].

Hydraulic jumps are required in the stilling basin to preserve the river geometry's structural integrity [25, 26]. Assume that the tailwater's depth does not meet the criteria. In that scenario, a negative slope (stair-shaped) is required to raise the water level downstream and reduce energy loss. It is necessary to alter the USBR Type III stilling basins.

4.4 USBR Type IV Stilling Basin

Type IV stilling basins are commonly used as energy dissipators in stilling basin structures [27]. It is designed to counter the problem of oscillating jump engaged with a generated wave that is difficult to dampen. It is applied in cases where the Froude number F_1 falls between 2.5 and 4.5. Low-head spillways and canal structures frequently have this range of Froude number [28].

5. STILLING BASIN APPURTENANCES

Stilling basins are a cost-effective means to reduce the problem of scouring but they are normally used along with other means of energy dissipation to enhance their performance. Baffle blocks, end sill, positive and negative steps, splitter block and buckets may be used as barriers or obstructions in the stilling basin to reduce the flow velocity and shorten the hydraulic jump length, resulting in better energy dissipation without increasing the water depth in the channel. As a result, there have been great efforts amongst engineers and researchers towards developing efficient but also cost-effective solutions [29-31].

The following are describing the most effective appurtenances in stilling basins;

5.1 Baffle Blocks

Also known as baffle piers. They serve to stabilize the flow and enhance turbulence over a shorter distance. This results in the primary mechanism for accelerating dissipation, which is the impinging action of the flow against the blocks, thereby maximizing the hydraulic drag force. This impinging action is also essential for significantly reducing the length of the stilling basin floor, which in turn decreases the civil structure and overall cost of the stilling basin.

Designs that optimize this drag force ratio have proven to be more effective than the conventional baffle block. Furthermore, optimized designs that utilize modified block shapes have demonstrated the ability to maximize this drag force ratio, leading to a greater reduction in energy over a shorter distance [32].

An experimental investigation was carried out by Ibrahim, 2017 to examine the effects of block shapes on the downstream flow pattern of a radial wall. The results indicated that the blocks were highly effective in mitigating the disconnection effect of the downstream flow pattern [33].

Wedge-shaped baffle blocks that do not protrude were used to investigate their impact on the characteristics of hydraulic jumps. The findings indicate that the length of the jump and the sequent depth ratio were reduced by 30% to 50% and 16.5% to 30%, respectively, in comparison to conditions with smooth beds [34].

Optimal performance can be achieved through the implementation of a two-row configuration of standard USBR baffle blocks, featuring blockage ratios of 50% and 375%, respectively. This setup should be utilized at specified distances, considering the sequential depth in relation to the velocity, ensuring an almost uniform distribution across the basin range [35].

Baffle blocks featuring a sloping vertical face located downstream of a sluice gate were experimentally investigated, to examine their effect on the length of the formed forced hydraulic jump. The findings indicate that baffle blocks with a sloping front face can decrease the length of the jump by roughly 48% in comparison to the free jump [36].

A cubic baffle blocks were designed to examine the influence of their location, relative size, and curvature (in plan) on the characteristics of hydraulic jumps and energy dissipation. The study revealed that the curved blocks exhibit an efficiency increase ranging from (3.2 to 33.3%) compared to a straight edge block in terms of dissipating excessive kinetic energy across all flow conditions [37].

5.2 End sill

An end sill can be characterized as a solid wall at the downstream end of the stilling basin that may be vertical, sloping, stepped, or dentated. It serves a crucial function in the design of stilling basins by shortening their length and improving the channel's downstream flow pattern [38].

The end sill, the final stabilizing component, directs the flow into the downstream channel and marginally deepens the water to stabilize the jump. A dentated sill, which has teeth or projections that divide the high-velocity flow

jet, increase aeration and flow fragmentation, decrease the concentrated impact area and large negative pressure zones that can cause cavitation, and produce the necessary energy dissipation while controlling the inherent dangers of high Fr flow, replaces the conventional solid end sill in high-velocity Type III basins.

In Accordance with the researcher Peterka, 1978 affiliated with the US Department of the Interior, Bureau of Reclamation, it is advised that dentate be installed on the side walls of the sill, while the continuous section of the end sill should have a slope of 2:1 for the USBR type II stilling basin [27].

Tiwari et al. (2011) conducted a review on the influence of end sills on the efficacy of non-circular pipe outlet models within the stilling basin. The authors concluded that the triangular end sill outperforms other types of end sills under the same flow conditions [39].

Tiwari et al. (2013) analyzed the hypothetically and experimentally submerged water-driven bounce within an outspread stilling basin equipped with a sudden drop. The authors noted that the sill diminishes the weight of the gate and the operational force, resulting in a more economical gate [40].

An experimental investigation was carried out to investigate the submerged flow through radial gates with and without a gate sill. The results show that the presence of sills adversely affects submerged radial gates [41].

An experimental study examining the effects of the sill on the Nagaa Hammadi regulator stilling basin was carried out.

The study focused on various factors, including the duration of reverse flow behind the sill, the pace at the end of the stilling basin, water dissipation, the length of the submerged hydraulic jump, and the configuration of the scour downstream of the regulator apron. The findings indicate that the sill positioned over the stilling basin significantly influences the flow characteristics and the local scour depth formed downstream, particularly for the upstream and downstream sills with correct and sloped faces [42].

5.3 Baffled chutes

Baffled chutes are multiple rows of baffle piers on the chute, mainly used as energy dissipation structures in chutes as well as in water conveyance and distribution systems. The process of energy dissipation within these structures takes place when the flow collides with the upstream side of the baffles that are installed in the chute [43].

A recent study showed that, in comparison to a chute without baffles, baffle chutes increased the aeration length by 5.8 times and the energy dissipation rate by 21–61% [44].

Zare and Doering investigated the impact of incorporating baffles and end sills on the energy dissipation of flow across stepped spillways featuring either sharp or rounded edges, along with an ogee inlet. Their findings indicated that the energy dissipation ratio for chutes with baffle edges surpassed that of chutes with still edges [45].

The United States Bureau of Reclamation (USBR) has performed comprehensive research on baffle block chutes to attain an ideal design. The guidelines provided by USBR suggest a slope of (2:1) for these chutes [46].

Figure 2 illustrates the specifics of a chute structure incorporating baffle blocks [47].

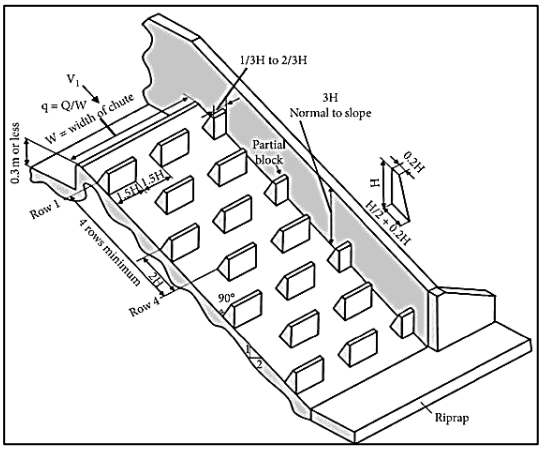

Fig 2. The elements of a chute with trapezoidal baffle blocks

According to Khatsuria, 2005, the positioning of baffles as an impact-type energy dissipater along the chute is a common practice. Nevertheless, it may not be cost-effective. It is recommended that a minimum of five rows of baffles be installed at the end of the chutes. These baffles will restrict flow acceleration between the rows and decrease the flow velocity at the toe of the chute [48].

In 2015, Valero and others conducted a numerical analysis on the impact of chute blocks regarding the length and stability of the hydraulic jump under both adverse conditions and design. The established model demonstrated a strong capability to replicate the variations in the stability and length of the hydraulic jump [49].

6. A COMPARATIVE ASSESSMENT OF DISSIPATION METHODOLOGIES

Among the various mentioned methodologies for energy dissipation, hydraulic jump stilling basins are recognized as the most dependable and widely utilized due to their predictable performance, structural simplicity, and robust empirical validation. Traditional USBR basins (Types I–IV) effectively convert supercritical flow to subcritical flow through turbulent jumps, achieving energy reductions of up to 60%; however, they necessitate substantial construction volume and are heavily reliant on suitable tailwater conditions. Trajectory methods, such as flip buckets, present lower initial costs and are particularly beneficial for high-head dams, yet they transfer energy dissipation to natural plunge pools, which introduces geological uncertainties and limits control over scour. Impact-type dissipaters and baffled chutes generate high turbulence and feature a compact design but may encounter issues with cavitation and maintenance. In comparison, stilling basins that are enhanced with optimized appurtenances such as baffle blocks, end sills, and baffled chutes offer the most balanced and efficient solution, merging hydraulic stability, economic viability, and adaptability to a diverse range of Froude numbers and flow regimes.

7. CONCLUSIONS

Efficient energy dissipation in hydraulic structures, including spillways and stilling basins, is vital to avert downstream scour and prevent structural failure. Traditional hydraulic jump techniques, impact-type dissipaters, and advanced appurtenances such as baffle blocks, end sills and baffled chutes are play critical roles in decreasing flow velocity and turbulence. The selection of design is affected by parameters such as Froude number and flow conditions, with optimized configurations improving stability and cost-effectiveness. The integration of these methods guarantees the structural integrity of hydraulic systems while reducing environmental and economic impacts.

Generally, a properly constructed conventional hydraulic jump stilling basin dissipates high percentage of the flow energy, up to 60%. However, recent research suggests that alterations to the internal geometry and boundary layer conditions may result in considerable enhancements in efficiency.

REFERENCES

[1] Alghwail ADA, Stević S, Abourohiem MA. Dissipation of mechanical energy over spillway through counter flow. *Građevinar*, **2018**,70(05), 378. https://doi.org/10.14256/JCE.1691.2016

[2] Alghwail ADA. Alleviation of the scouring problem downstream of dam spillways through a reversed cross¬-jet flow dissipator. The 8th International Conference on Scour and Erosion, Oxford, UK, (12-15 September 2016).

[3] Novak P., Moffat I.,Nalluri C., Narayanan R., Hydraulic Structures, 4th ed., E & FN Spon, New York, **2007**.

[4] Vischer D. L., and W. H. Hager, Energy Dissipators, Hydraulic Design Considerations, *IAHR*, 1995.

[5] H. Wayne Coleman; C. Y. Wei; James E. Lindell; Larry W. Mays. Hydraulic Design of Spillways, 1st ed.; U.S. Army Corps of Engineers. Washington, USA, **1992**, DC 20314-1000.

[6] Rahatabad, Farhad Golzari. Effect Of Using Dentate Ski Jump Spillways on Scouring Profile, In: Chiew, Yee-Meng; Lim, Siow-Yong; Cheng, Nian-Sheng (Hg.): Proceedings 2nd International Conference on Scour and Erosion (ICSE-2), Singapore. Singapore: Nanyang Technological University, (14.–17 November 2004).

[7] Singh D, Kumar M. Energy dissipator in different types of hydraulic structures -A review. In Dams & Hydraulic Structures. New Delhi, India: Indian Association of Structural Engineers; 2022.

[8] CHANSON H. Current knowledge in hydraulic jumps and related phenomena. *European Journal of Mechanics B/Fluids*, **2009**. 28(2), 191–210.

[9] Alghwail ADA. Experimental study of drowned hydraulic jump characteristics through different counterflow dimensions. The 3rd Conference for Engineering Sciences and Technology (CEST-2020), Elmergib University, Alkhums, Libya. (1-3 December 2020).

[10] Bhowmik, Nani G. Hydraulic Jump Type Stilling Basins for Froude Number 2.5 to 4.5. Illinois State Water Survey, *Urbana, Report of Investigation* 67, **1971**.

[11] Bradley, J.N. & Peterka, A. J., Hydraulic design of stilling basins. *Journal of A.S.C.E., Hydraulic Engg*., **1957**. 83 (5), 1401-1406.

[12] Fiala, J. R. & Maurice, L. A. Manifold stilling basins. *Journal of A.S.C.E., Hydraulic Div*., **1961**. 87 (4), 55-81.

[13] Keim, S. R. Contra costa energy dissipator. *Journal of A.S.C.E., Hydraulic Division*, **1962**, 3077, 109-122.

[14] Vollmer, E., Khader, M.H.A. Counter current energy dissipator for conduit outlets. *International J. of Water Power*, **1971**. 23 (7), 260-263.

[15] Verma, D.V.S & Goel, A. Stilling basins for outlets using wedge shaped splitter blocks. *ASCE Journal of Irrigation and Drainage Engineering*, **2000**. 126 (3), 179-184.

[16] Verma, D.V.S. & Goel, A. Development of efficient stilling basins for pipe outlets. *ASCE Journal of Irrigation and Drainage Eng*., 2003 129 (3), 194-200.

[17] Goel, A., Design of stilling basin for circular pipe outlet. *Canadian Journal of Civil Engineering*, **2008**, 35 (12), 1365-1374.

[18] Tiwari, H.L. & Gahlot, V. K. Experiments on new Stilling basin for Pipe outlets. *STM, AISECT University*, **2012**, 2 (2), 17-20.

[19] Tiwari, H.L. & Goel, A. Effect of end sill in the performance of stilling basin. *American Journal of Civil Engg. and Architecture*, **2014**, 2 (2), 60-63.

[20] Tiwari, H.L. & Goel A. Effect of impact wall on energy dissipation in stilling basin. *KSCE Journal of Civil Engg.*, **2016**, 20 (1), 463-467.

[21] Khadka, Dak Bahadur. Experimental Study on USBR Type Stilling Basin Design Article Information Abstract. *International Journal of Social Sciences and Management*, **2024**, 11. 17-26. 10.3126/ijssm.v11i1-2.62867.

[22] David M. Admiraal; Chi Zhang, Energy Dissipation Optimization for Circular Culverts. Department of Civil and Environmental Engineering, Nebraska University, Lincoln: Final Report, **2023**.

[23] Gebhardt, M., Pfrommer, U., Rudolph, T., Thorenz, C., Numerical and physical study on the energy dissipation at inflatable gates. In 7th IAHR International Symposium on Hydraulic Structures, **2018**, 174-183. https://doi.org/10.15142/T3JD26

[24] Hassanpour, N., Hosseinzadeh Dalir, A., Bayon, A., Abdollahpour, M., Pressure fluctuations in the spatial hydraulic jump in stilling basins with different expansion ratio, *Water*, **2020**, 13(1), 60. https://doi.org/10.3390/w13010060

[25] Soori, S., Babaali, H., Soori, N., An optimal design of the inlet and outlet obstacles at USBR II Stilling Basin. *International Journal of Science and Engineering Applications*, **2017**, 6(5), 134–142. https://doi.org/10.7753/ijsea0606.1001

[26] Bhate, R.R., Bhajantri, M.R., Bhosekar, V.V., Mitigating cavitation on high head orifice spillways. *ISH Journal of Hydraulic Engineering*, **2021**, 27(3), 235-243. https://doi.org/10.1080/09715010.2018.1547990.

[27] Peterka, A. J., Hydraulic design of stilling basins and energy dissipator, Engineering *Monograph, No. 25*. Bureau of Reclamation, United States Department of the Interior. Washington, D.C., **1978**.

[28] Abdel AAL G.M., et al., Improving energy

dissipation on stepped spillways using breakers. *Ain Shams Engineering Journal*, **2018**, 9(4), 1887–1896.

[29] Novak, P. et al., Hydraulic Structures. London: Spon Press, **2001 and 2006**.

[30] Manoochehr, F., et al., Reduction of Stilling Basin Length with Tall End Sill. *Journal of Hydrodynamics*, **2011**. 23 (4), 498-502.

[31] Verma, D.V.S., Stilling Basins for Pipe Outlets Using Wedge-Shaped Splitter Block. *Journal of Irrigation and Drainage Engineering*, **2000**, 126 (3), 179-184.

[32] Abbas A., Alwash H. and Mahmood A., Effect of baffle block configurations on characteristics of hydraulic jump in adverse stilling basins MATEC Web Conf., Sharm el-Shiekh, Egypt, (23-25 October 2017).

[33] Ibrahim M. M., Improve the Efficiency of Stilling Basin Using Different Types of Blocks, American *Journal of Engineering Research (AJER)*, **2017**, 6 (8), 295-304.

[34] Ellayn A. F., and Zhi-lin Sun., Hydraulic Jump Basins with Wedge-Shaped Baffles, *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering*, **2012**, 13(7), 519-525.

[35] Elevatorski, Edward, A. Hydraulic Energy Dissipators. McGraw Hill Book Company, Inc., New York. **1959**.

[36] Nabil B., and Rezak A.A., Effect of Baffle Blocks with Sloping Front Face on the Length of the Jump, *Journal of Civil Engineering the Institute of Engineers, Bangladesh*, **2002**, 30 (2),101-108.

[37] Eloubaidy A.F., Al-Baidhani J.H., and Ghazali A.H., Dissipation of Hydraulic Energy by Curved Baffle Blocks, *Pertanika Journal of Science and Technology*, **1999**, 7(1), 69-77.

[38] aafar S. Maatooq & Enass R. Taleb, The Effects of Baffle Blocks Locations and Blockage Ratio on the Sequent Depth and Velocity Distribution of Forced Hydraulic Jump, 7th International Symposium on Hydraulic Structures, Aachen, Germany, (15-18 May 2018).

[39] Tiwari, H. L., A. Goel, and V. K. Gahlot., Experimental study of sill controlled stilling basins for pipe outlet, *International Journal of Civil Engg. Research 2*, **2011**, no. 2, 107-117.

[40] Tiwari HL, Gahlot VK, Tiwari S., Reduction of scour depth downstream of pipe outlet stilling basin using end sills, *International Journal of Engineering Sciences*, **2013**, 2(7), 20-25.

[41] Abdelhaleem F.S., Hydraulics of submerged radial gates with a sill, *ISH Journal of Hydraulic Engineering*, **2017**, 23(2), 177-186. doi:10.1080/09715010.2016.1273798.

[42] Mohamed YA, Saleh YK, & Ali AM., Studying the effect of different configuration of sill over stilling basin on flow characteristics behind radial gate, (Case Study Naga Hammadi Regulator), *JES, Assiut University, Faculty of Engineering*, **2015**, 43(3), 311- 329.

[43] Rafiei H., Jalal Bazargan J., Babakhani A., Effect of Geometric Arrangement of the Baffles on the Energy Dissipation Rate of the Baffled Chutes, *Iranian Journal of Irrigation and Water Engineering*, **2022**, 49(1), 51-65.

[44] Daneshfaraz R., Ghaderi A., Bagheri A., Experimental Study of Block Geometry on Aeration and Energy Dissipation at Baffled Chutes, *Civil Infrastructure Researches (CIR)*, **2023**, 8(2), 103-114.

[45] Zare H. K. and Doering J. C., Energy dissipation and flow characteristics of baffles and sills on stepped spillways, *Journal of Hydraulic Research*, **2012**, 50(2) 192–199, https://doi.org/10.1080/00221686.2012.659840, 2-s2.0-84859698962.

[46] Peterka A., Hydraulic Design of Stilling Basins and Energy Dissipators, *Engineering Monograph No. 25*, 1964, U. S. Department of Interior, Bureau of Reclamation, Socorro, NM, USA.

[47] Kaya N. and Emiroglu M. E., Study of oxygen transfer efficiency at baffled chutes, *Proceedings of the Institution of Civil Engineers-Water Management*, **2010**, 163(9), 447–456. https://doi.org/10.1680/wama.900029, 2-s2.0-79958185800.

[48] Khatsuria R. M., Hydraulic of Spillway and Energy Dissipators, *Jurnal Teknik Sipil ITB* ,**2009**, 26(1) 33-38.

[49] Valero,D., Garcia-Bartual,R., & Marco, J., Optimisation of Stilling Basin Chute Blocks Using a Calibrated Multiphase RANS Model. In Proc, 5thInternational Junior Researcher and Engineer Workshop on Hydraulic Structures. Spa, Belgium, (28-30 August 2015).