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IMPROVING THE HYDRAULIC CALCULATION METHOD FOR WATER DISCHARGE STRUCTURES

Rakhmatov, Makhmud – Candidate of Technical Sciences, Associate professor,
E-mail: rahmatov1959@mail.ru, ORCID: 0009-0008-0759-9841, Science ID: FQD-0426-0107;
Bobomurodov, Furkat – Doctor of Philosophy (PhD) in Technical Sciences, Associate professor,
E-mail: furqatbobomurodov709@gmail.com, ORCID: 0009-0002-0055-6343,
Science ID: FQD-1125-0065;
Khazratov, Alisher – Doctoral student (PhD), ORCID: 0009-0003-8764-1125,
E-mail: alisherhazratov5354@gmail.com, Science ID: MQD-0225-0015;
Payanova, Iroda– Master's student
E-mail: irodapayanova@gmail.com, Science ID: MQD-0626-0069.

Karshi State Technical University, Karshi city, Uzbekistan

Abstract. *Dams whose failure may pose a threat to human life or result in substantial economic losses must be designed to safely withstand the Probable Maximum Flood (PMF). In Uzbekistan, the impacts of climate change, irregular precipitation patterns, and accelerated glacier melting in mountainous regions have increased the likelihood of extreme flood events. Consequently, some existing spillways may no longer fully satisfy current design requirements. Therefore, the rehabilitation and modernization of hydraulic structures, particularly dam spillways, together with the enhancement of their hydraulic performance, have become important engineering challenges.*

Another critical issue is the high sediment load observed in many reservoirs located within the Amudarya and Syrdarya river basins. For this reason, sediment transport and deposition processes should be carefully considered when upgrading spillway systems. The discharge capacity of spillways can be improved through the application of specialized hydraulic structures. For example, labyrinth spillways are capable of increasing discharge per unit width; however, under conditions of high sediment concentration, they may promote sediment accumulation upstream of the structure.

In this context, stepped spillways represent a promising alternative. Characterized by an inclined labyrinth-type configuration, these structures provide greater hydraulic efficiency than conventional linear spillways. Under identical head and width conditions, stepped spillways are capable of conveying significantly larger flow rates. This advantage allows reservoirs to operate at higher storage levels, increases available water reserves, and contributes to more efficient utilization of water resources. Their application is particularly beneficial in mountainous and topographically constrained areas where expanding spillway width is difficult or economically impractical.

Previous investigations have demonstrated that the stepped spillway configuration improves hydraulic performance by reducing the upstream head over the crest and lowering the risk of overtopping. Although the magnitude of head reduction decreases slightly as discharge increases, the improvement remains substantially greater than that achieved by traditional rectangular spillways across all tested flow conditions.

Keywords: *dam, spillway, hydraulic structure, stepped spillway, discharge capacity, hydraulic efficiency, sediment transport.*

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SUV TASHLASH INSHOOTINI GIDRAVLIK HISOBLASH USULINI TAKOMILLASHTIRISH

Raxmatov Mahmud Ismatovich – texnika fanlari nomzodi, dotsent;
Bobomurodov Furqat Farxod o'g'li – texnika fanlari bo'yicha falsafa doktori (PhD), dotsent;
Hazratov Alisher Rahmatillo o'g'li – tayanch doktorant;
Payanova Iroda Sherbuta qizi – magistrant.

Qarshi davlat texnika universiteti, Qarshi sh, O'zbekiston

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Annotatsiya. *Buzilishi insonlar hayotiga xavf tug‘dirishi yoki katta miqdordagi moddiy zarar keltirishi mumkin bo‘lgan to‘g‘onlar ehtimoliy maksimal suv toshqiniga bardosh beradigan qilib loyihalanishi zarur. O‘zbekiston sharoitida ham iqlim o‘zgarishi, yog‘in miqdorining notekis taqsimlanishi hamda tog‘ hududlarida muzliklar erishi natijasida ekstremal suv oqimlari ehtimoli ortib bormoqda. Bu esa mavjud suv tashlagichlarning ayrim hollarda loyihaviy me’yorlarga to‘liq javob bermasligiga olib kelmoqda. Shu sababli respublikamizdagi mavjud gidrotexnik inshootlar, xususan to‘g‘on suv tashlagichlarini rekonstruksiya qilish va ularning gidravlik samaradorligini oshirish dolzarb masalalardan biri hisoblanadi.*

O‘zbekistonning Amudaryo va Sirdaryo havzalarida joylashgan ko‘plab suv omborlarida oqiziqlar (sedimentlar) miqdorining yuqoriligi ham muhim omillardan biridir. Shu bois suv tashlagichlarni modernizatsiya qilishda oqiziqlar ta’sirini hisobga olish talab etiladi. Maxsus oqimga ega gidrotexnik inshootlar qo‘llash orqali suv tashlagichlarning o‘tkazish qobiliyatini oshirish mumkin. Jumladan, labirintsimon suv tashlagichlar birlik kenglikka to‘g‘ri keladigan suv sarfini oshirish imkonini beradi, biroq katta miqdordagi oqiziqlar mavjud sharoitda ularning ortida cho‘kindi to‘planishi ehtimoli yuqori bo‘ladi.

Shu nuqtai nazardan, “pog‘onasimon suv tashlagich” shaklidagi suv tashlagichlar istiqbolli yechim sifatida qaraladi. Ushbu turdagi suv tashlagichlar qiyalama labirintsimon konstruktsiyaga ega bo‘lib, an’anaviy to‘g‘ri chiziqli suv tashlagichlarga nisbatan yuqori gidravlik samaradorlikni ta’minlaydi. Bir xil bosim va kenglik sharoitida ular orqali o‘tuvchi suv sarfi sezilarli darajada ortadi. Bu esa suv omborlarini nisbatan yuqori sathlarda ishlatish, suv zaxirasini ko‘paytirish hamda suv resurslaridan samarali foydalanish imkonini beradi. Ayniqsa, tog‘li va relefi murakkab hududlarda, suv tashlagich kengligini oshirish imkoniyati cheklangan hollarda “pog‘onasimon suv tashlagich” juda qulay hisoblanadi.

Tadqiqotlar shuni ko‘rsatadiki, pog‘onasimon suv tashlagich konstruksiyasi suv tashlagich qirrasi ustidagi bosimni kamaytirish orqali uning gidravlik samaradorligini oshiradi va suv bosishi xavfini pasaytiradi. Suv sarfi ortishi bilan bosim kamayish darajasi biroz qisqarsada, barcha holatlarda u an’anaviy to‘rtburchakli suv tashlagichlarga nisbatan sezilarli darajada yuqori bo‘lib qoladi.

Kalit so‘zlar: *to‘g‘on, suv tashlagich, suv o‘tkazgich; pog‘onasimon suv tashlagich, solishtirma oqim.*

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Рахматов Махмуд Исматович – кандидат технических наук, доцент;
Бобомуродов Фуркат Фарход угли – доктор философии (PhD) по техническим наукам, доцент;
Хазратов Алишер Рахматилло угли – докторант;
Паянова Ирода Шербута кизи – магистрант.

Каршинский государственный технический университет, г. Карши, Узбекистан

Аннотация. *Плотины, разрушение которых может представлять угрозу для жизни населения или привести к значительным материальным потерям, должны проектироваться с учетом пропуска вероятного максимального паводка. В условиях Узбекистана вероятность возникновения экстремальных расходов воды возрастает вследствие изменения климата, неравномерного распределения атмосферных осадков и интенсивного таяния ледников в горных районах. В результате существующие водосбросные сооружения в ряде случаев перестают в полной мере соответствовать современным проектным требованиям. В связи с этим реконструкция действующих гидротехнических сооружений, в частности водосбросов плотин, а также повышение их гидравлической эффективности являются актуальными задачами.*

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Одним из важных факторов для водохранилищ, расположенных в бассейнах рек Амударьи и Сырдарьи, является высокая концентрация наносов. Поэтому при модернизации водосбросов необходимо учитывать влияние процессов переноса и отложения наносов. Повышение пропускной способности водосбросов возможно за счет применения гидротехнических сооружений специальной конструкции. В частности, лабиринтные водосбросы позволяют увеличить удельный расход воды на единицу ширины, однако при значительном содержании наносов существует высокая вероятность их аккумуляции перед сооружением.

С этой точки зрения перспективным решением являются ступенчатые водосбросы. Данный тип сооружений имеет наклонную лабиринтную конструкцию и обеспечивает более высокую гидравлическую эффективность по сравнению с традиционными прямолинейными водосбросами. При одинаковых значениях напора и ширины водосброса через них может пропускаться значительно больший расход воды. Это позволяет эксплуатировать водохранилища при более высоких уровнях воды, увеличивать объем аккумулируемых водных ресурсов и повышать эффективность их использования. Особенно эффективны ступенчатые водосбросы в горных и сложных по рельефу районах, где возможности увеличения ширины водосбросного фронта ограничены.

Результаты исследований показывают, что конструкция ступенчатого водосброса способствует снижению напора над гребнем водослива, тем самым повышая его гидравлическую эффективность и уменьшая риск затопления верхнего бьефа. Несмотря на то, что с увеличением расхода воды степень снижения напора несколько уменьшается, во всех исследованных случаях данный показатель остается существенно выше по сравнению с традиционными прямоугольными водосбросами.

Ключевые слова: *плотина, водосброс, водопропускное сооружение, ступенчатый водосброс, удельный расход, гидравлическая эффективность*

Introduction

The impacts of climate change on mountainous river basins have become increasingly significant, contributing to accelerated erosion processes, a higher frequency of natural disasters, and adverse effects on agricultural productivity, thereby threatening food security. In Central Asia, particularly in Uzbekistan, recent years have witnessed a growing occurrence of extreme precipitation events and rapid melting of snowpacks and glaciers in mountainous regions, resulting in substantial increases in river discharge [1, 2, 3].

Under these circumstances, predicting reservoir inflows with a high degree of accuracy becomes difficult. During periods of intense rainfall, reservoir water levels may rise rapidly, increasing the risk of dam overtopping. Such conditions can compromise the operational reliability of hydraulic structures and potentially lead to serious structural failures and emergency situations.

Numerous studies indicate that insufficient spillway capacity is one of the principal factors contributing to dam safety problems. Consequently, accurate determination of spillway design capacity and the adaptation of existing structures to meet modern engineering requirements are essential for ensuring the safe operation of hydraulic infrastructure [4, 5].

Increasing spillway discharge capacity is commonly achieved through the construction of additional spillway facilities. However, many reservoirs in Uzbekistan are situated in mountainous or heavily developed regions, where the construction of new hydraulic structures is often constrained by technical, economic, and environmental considerations. Therefore, the rehabilitation and modernization of existing spillways have emerged as more practical and cost-effective alternatives.

Conventional spillways generally possess limited flow-conveyance capacity and may be unable to safely pass extreme flood discharges. Furthermore, excessive hydraulic head over the spillway crest can lead to submergence effects, which reduce discharge efficiency and negatively affect overall hydraulic performance [6].

In view of these challenges, the development and implementation of innovative spillway configurations with enhanced hydraulic characteristics have become increasingly important. Such

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solutions are essential for improving the safety and operational reliability of both existing and newly constructed dams under the evolving conditions associated with climate change.

Nomenclature

B_T – total crest length;

B – base length;

B_0 – upstream crest length;

B_i – downstream crest length;

P_i – inlet section height;

W_i – inlet width (measured between the sidewalls);

W_0 – outlet width (measured between the sidewalls).

Research Methodology

A stepped spillway represents an advanced modification of the conventional labyrinth spillway and is recognized for its superior hydraulic performance compared with traditional linear spillways. Owing to its increased effective crest length, the structure is capable of conveying substantially greater discharge per unit width under identical head and spillway width conditions (Figure 1). One of its practical advantages is the possibility of installation directly on the crest of existing dams, making it an attractive option for rehabilitation and upgrading projects [7].

The ability of stepped spillways to pass larger flow rates under relatively low heads has made them a promising solution for improving the capacity of existing hydraulic structures. Previous studies have demonstrated that, under comparable hydraulic conditions, stepped spillways exhibit greater discharge efficiency than conventional labyrinth spillways. This enhanced performance is primarily attributed to their geometric configuration, which increases the effective flow area while maintaining a compact structural footprint.

The protruding upstream section of a stepped spillway enlarges both the inlet flow area and the wetted perimeter. As a result, the approach velocity decreases, flow contraction effects are reduced, and hydraulic energy losses become less significant. These characteristics contribute to improved flow conveyance and greater overall hydraulic efficiency.

From a hydraulic engineering perspective, stepped spillways are transverse river structures that modify local flow patterns and influence the hydraulic regime of the channel. Similar to traditional dams and weirs, whether triangular or rectangular in shape, they play an important role in regulating upstream water levels and supporting efficient utilization of available water resources.

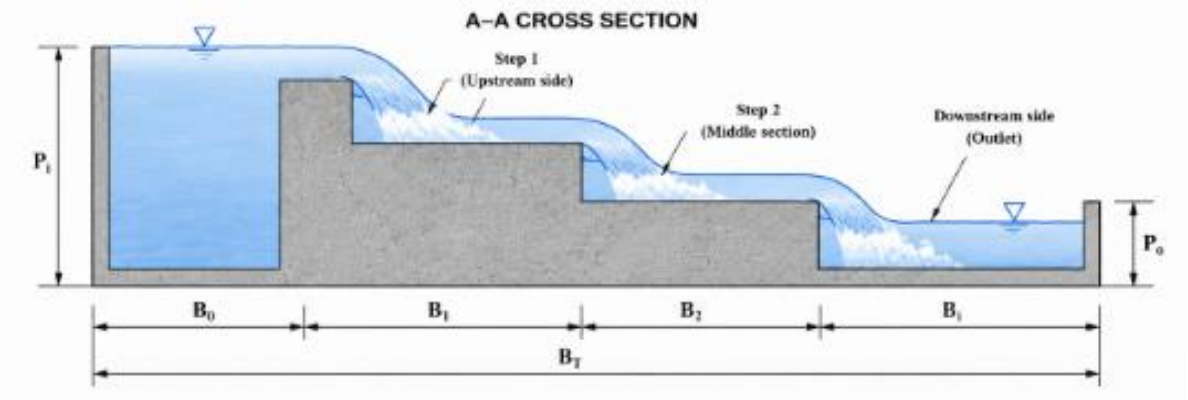

Fig 1. Geometry of a stepped spillway structure.

Despite these advantages, such structures may affect the natural continuity of sediment transport. Increased upstream water depth often results in reduced flow velocity, limiting the ability of the flow to carry sediment downstream. Consequently, sediment deposition may occur upstream

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of the structure, gradually altering channel morphology and potentially affecting the surrounding aquatic environment [8, 9].

This issue is particularly relevant in Uzbekistan, where reservoirs within the Amudarya and Syrdarya basins are characterized by high sediment loads. Therefore, sediment transport dynamics and deposition processes should be carefully considered when evaluating the applicability and long-term performance of stepped spillway systems [10].

Nevertheless, because stepped spillways do not completely obstruct river flow and generally cause less disturbance to natural flow conditions than many conventional structures, they may offer an alternative approach for maintaining sediment continuity within river systems. To fully assess their hydraulic and environmental impacts, comprehensive experimental investigations and theoretical analyses of the flow processes occurring around stepped spillways are required.

The experimental investigation was conducted in the Hydraulic and Hydraulic Structures Laboratory of the Department of Hydraulic Engineering and Hydraulic Structures at Karshi State Technical University. The primary objective of the study was to evaluate the reduction of hydraulic head over a stepped spillway under open-channel flow conditions (Figure 2).

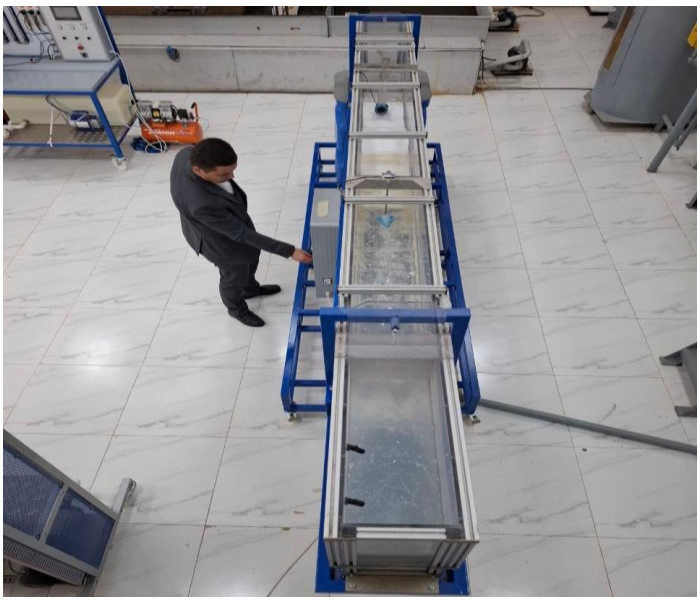

Fig 2. Experimental Setup.

The experimental facility consisted of a rectangular flume with dimensions of 0.30 m in width, 0.40 m in height, and 3.0 m in length. A physical model of a stepped spillway was fabricated and installed within the flume. The model comprised inlet and outlet sections connected through a stepped flow path designed to enhance hydraulic performance.

The internal spacing between the inlet and outlet sections was maintained at 77 mm, while the wall thickness was fixed at 7 mm. To ensure geometric stability and consistency of the model, the ratio between the base length and the protruding sections on both the upstream and downstream sides was maintained at 1:1.

The overall dimensions of the spillway model were 1000 mm in length and 200 mm in height. During the experiments, the discharge was varied between 4,700 cm^3/s and 12,000 cm^3/s using flow-control valves, while subcritical flow conditions were maintained throughout all test runs. This experimental arrangement enabled a detailed assessment of the hydraulic behavior and performance of the stepped spillway under different flow conditions.

Results and Discussion

To evaluate the hydraulic performance of the stepped spillway, a series of experiments were conducted under twelve different hydraulic conditions. The primary objective was to determine the head over the spillway crest and compare its behavior with that of a conventional rectangular

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spillway. Throughout all experiments, the bed material characteristics were kept constant, with an average particle diameter of d=0.25 mm.

The experimental results demonstrated a substantial reduction in the hydraulic head above the stepped spillway crest. At the maximum tested discharge of Q=12,000 cm³/s, the measured head was 1.63 cm, whereas the corresponding head over the conventional rectangular spillway reached 5.57 cm. Similarly, under the minimum discharge condition of Q=4,700 cm³/s, the head above the stepped spillway was only 0.60 cm, compared to 2.96 cm for the traditional spillway.

During the experiments, the flow discharge was regulated using control valves to maintain stable hydraulic conditions. The observed results clearly indicate that the stepped spillway provides considerably better hydraulic performance than the conventional rectangular configuration. The reduction in head over the crest reflects an increase in flow conveyance efficiency and a lower tendency for upstream water level rise.

The complete set of experimental data is presented in Table 1, which further illustrates the superior hydraulic characteristics of the stepped spillway under varying discharge conditions. Overall, the results confirm that the proposed stepped geometry significantly enhances spillway efficiency and contributes to improved hydraulic performance compared with conventional designs.

Table 1. Experimental Results

Consumption, Q (sm³/s)	Pressure above the stepped spillway (cm)	Pressure above conventional spillway (cm)
10600	1.35	5.13
9300	1.21	4.69
8800	1.04	4.52
8200	0.99	4.30
12000	1.63	5.57
4700	0.60	2.96
5600	0.63	3.33
6700	0.78	3.77
7500	0.83	4.06
8200	0.94	4.32
9600	1.21	4.78
10400	1.32	5.04

The experimental results indicate that the percentage reduction in hydraulic head was greater at lower flow discharges and gradually decreased as discharge increased. Nevertheless, the reduction remained above 70% under all tested conditions. Statistical analysis revealed a strong linear trend, with a coefficient of determination of R^2=0.892, demonstrating a high correlation between flow discharge and head reduction (Figure 3).

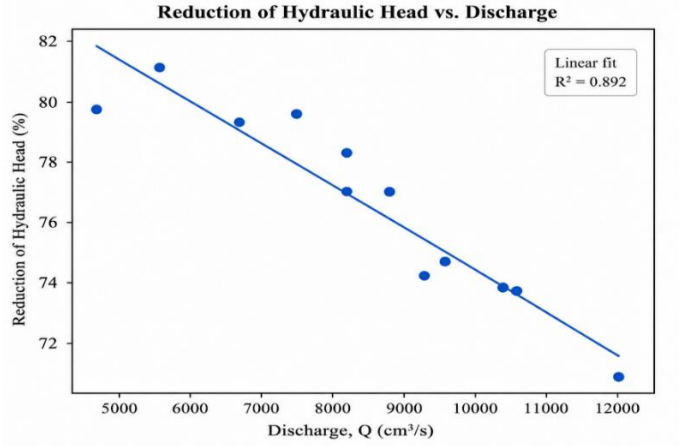

Fig 3. Percentage Reduction in Hydraulic Head Relative to a Conventional Rectangular Measuring Weir.

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Conclusions

The hydraulic performance of the proposed stepped spillway was investigated under various flow conditions. Owing to its increased effective crest length, the stepped spillway demonstrated a significantly greater discharge capacity than conventional spillway configurations. Since the hydraulic head above the spillway crest is a critical parameter influencing upstream water levels and overtopping risk, its behavior was examined in detail throughout the study.

The experimental results revealed a substantial reduction in hydraulic head when the stepped spillway was employed. Compared with a conventional rectangular spillway, the measured head reduction exceeded 70% under all tested discharge conditions, highlighting the superior hydraulic efficiency of the proposed design. As a consequence, upstream water levels are lowered, thereby reducing overtopping risk and enhancing the overall safety of hydraulic structures.

Another notable advantage of stepped spillways is their ability to regulate flow without completely obstructing the river channel. This characteristic enables their application in flow regulation and temporary water retention systems while maintaining a relatively natural flow regime. Consequently, stepped spillways may be considered a more environmentally sustainable alternative to conventional flow-control structures.

One of the major challenges associated with river valley development projects, particularly during low-flow periods, is the disruption of natural river continuity caused by traditional dam structures. Such limitations often hinder the implementation of economically viable and socially beneficial water management projects. In contrast, stepped spillways provide a practical solution by allowing continuous flow passage while still offering effective hydraulic regulation.

Furthermore, stepped spillway technology operates without the need for conventional gated control systems and does not completely block river flow. The structure can also increase water storage within the river channel itself while minimizing the need for extensive relocation, reconstruction, or rehabilitation works. These characteristics contribute to lower construction and maintenance requirements compared with many traditional hydraulic structures.

Therefore, the application of stepped spillway technology can be regarded as a promising approach for enhancing the efficiency and safety of hydraulic infrastructure in Uzbekistan. Its implementation may be particularly beneficial for the modernization of existing reservoirs and the development of innovative hydraulic engineering solutions capable of meeting future water management challenges.

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