ENERGY DISSIPATOR IN HYDRAULIC STRUCTURE – A REVIEW

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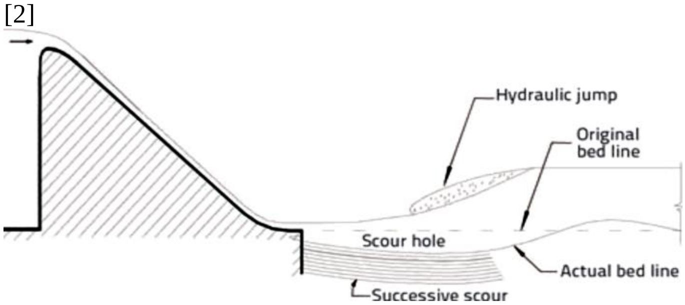
ABSTRACT: *Energy dissipator is a device designed to protect downstream areas from erosion by minimizing the flow velocity up to an acceptable limit. It is an important element of hydraulic structures as a transition between the high-velocity flow and the sensitive tailwater. This paper reviews energy dissipators in connection with dam and spillway structure. This paper also describes the different types of energy dissipators with different appurtenances used in hydraulic structures for protection work. It includes topics such as energy dissipation of block ramp, hydraulic jump type stilling basin, stepped spillway, and the deflector (flip bucket and ski-jump bucket).*

Keywords: Energy Dissipation, Block Ramp, Stepped Spillway, Stilling Basin, Hydraulic Jump, Flip Bucket, Ski-jump Bucket.

1. INTRODUCTION

A dam is basically a man-made hydraulic structure built across a valley to provide sufficient water to users. However, there is a risk of dam overtopping during the extreme flood where the inflow of water increase and raise the reservoir level due to major rainfall situation. To dispose surplus of water from the upstream to downstream effectively, the spillway system can be designed to pass safely floodwaters above, below, within or around the dam. [1]

Because of the conversion of whole potential energy into kinetic energy, water flowing over a spillway has a very high kinetic energy. Thus, serious scour of channel bed as illustrated in Figure 1 may occur due to the high velocity of water that is discharged through the spillway or pipe outlet. [2]



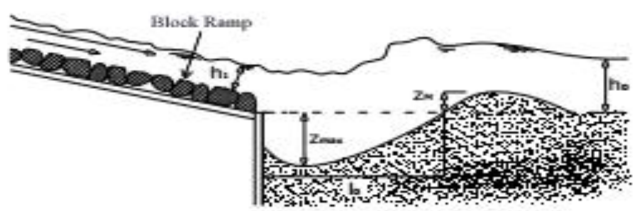
Fig(1) Scour process downstream of a spillway [2]

Along these lines, a hydraulic energy dissipator can be introduced as a device to protect the downstream area by scaling down the velocity of the flow to an acceptable limit. There are several types of energy dissipation devices that have been tried so far; i) Energy dissipation of block ramp ii) Hydraulic jump type stilling basin, iii) Stepped spillway, and iv) Deflector – Flip bucket and ski-jump bucket. [3] Furthermore, the devices may be used as a barrier or obstruction to reduce the velocity of the flow resulting in better energy dissipation. [4]

2. TYPE OF ENERGY DISSIPATOR

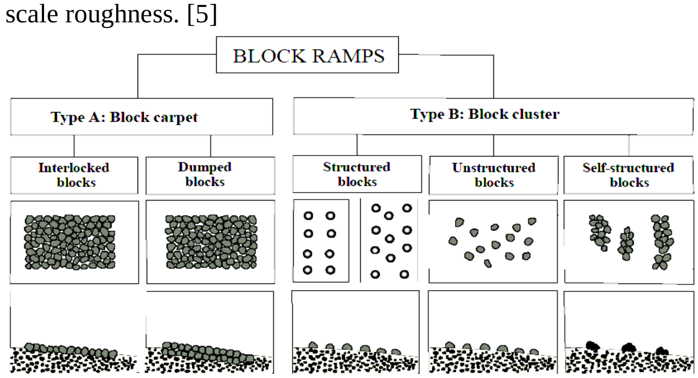
2.1 Energy Dissipation of block ramps

Block ramps are naturalistic stream structures which often used to satisfy a correct balance between hydraulic functioning and environmental impact. [1] Figure 2 shows the illustration of the block ramp on the spillway. According to Pagliara, block ramps give a minor environmental impact compared to traditional hydraulic structures such as sills and check dams that usually became a barrier for fish migration, present problems of landscape insertion, and sometimes reduce the solid transport. [5] Due to the large roughness, block ramps have been classified as an effective dissipation for the energy at the downstream of hydraulic structures such as spillways, overflow dams, and trench weirs. Morphological and structural classification of block ramps is illustrated in Figure 3. [6]



Fig(2) Scour process downstream of a spillway [9]

Various studies have been conducted to study the numerous aspects of block ramps. Pagliara and Chiavaccini [7] conducted an experiment to study the energy dissipation caused by the presence of a block ramp. With different bed materials, ranging from very coarse sand to small cobbles, the experiment is conducted on-ramps, considering the different slope of bed ranging from 1V:4H to 1V:12H. Essentially, the amount of energy dissipation is a function of the slope, the relative submergence, and the ration between the length of the slope and the critical water depth. Through this study, it can be concluded that the energy dissipation decrease with the slope of the ramp and from small scale roughness to large scale roughness. [5]

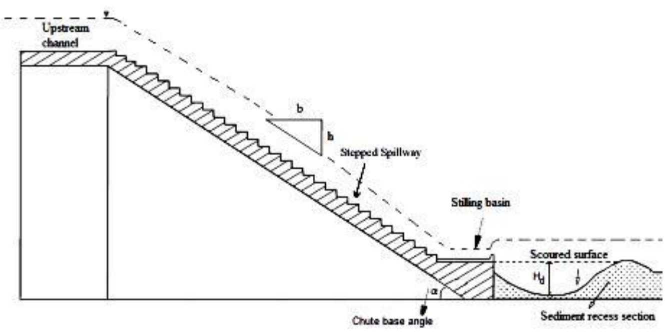


Fig(3) Morphological and structural classification of block ramps [6]

Zulfequar et al [8] studied the effect of energy dissipation at the block ramp with the existence of boulders on the bed. The experiment is conducted on a ramp where the boulders are hemispherical in shape, arranged in a staggered layout with base material on its bed. The author experienced that staggered arrangement contributes to the higher dissipation of energy in correlation to the boulder with random arrangements. Not only depends on discharge flow, but relative energy dissipation also depends on the concentration and the size of boulders. Furthermore, in comparison to the smooth base material, the author noticed that the dissipation of energy was considerably improved in conjunction to the resistance of flow resistance by the staggered arrangement of the boulders placed over the ramp. It shows that the relative dissipation of energy increases with the decrease of the boulder's spacing.[8]

2.2 Stepped Spillway and Cascade

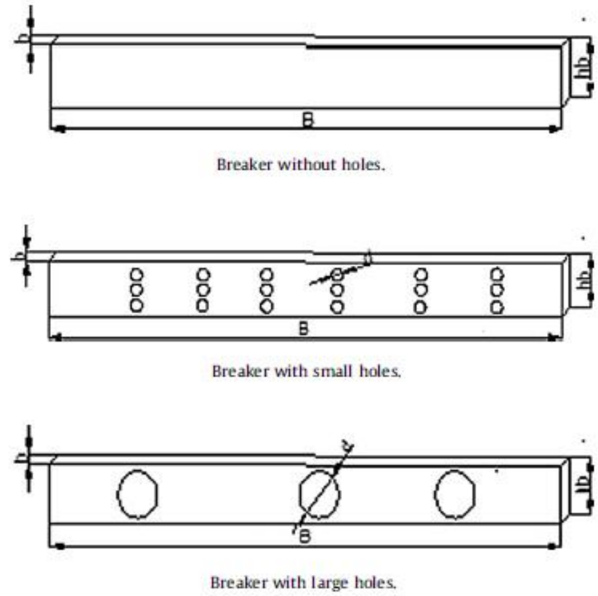
A system of the spillway is an opening intended to spill securely the floodwater. The spillway is also required to dissipate the turbulent kinetic energy of the flow before it rejoins the natural river channel. Figure 4 shows a schematic diagram for a stepped spillway.



Fig(4) Stepped spillway schematic diagram [10]

The construction of steps on spillway contributes to the dissipation of the energy, subsequently diminishing the measure of downstream stilling structure. [3] Many studies, as well as engineering practices, show that the aeration of flow and the vortex on the steps may dissipate the energy of the flow. [11] According to Roushangar et al [12], the acceleration and final velocity of the flow may be reduced as the steps in the spillway act as roughness elements. The author believed that a stepped spillway has a stepped ogee-profile spillway instead of the traditional smooth ogee-profile spillway, where a series of drops are made in the invert from the area of the crest to the toe. [12]

Gamal et al [13] investigated the over-flow, through flow and under-flow breakers in the stepped spillway. In the investigation, the author constructed a physical model of four steps to evaluate their effect in dissipating the energy. Breakers are installed over the steps of the spillway, providing three types of the breaker as shown in Figure 5. The experiment resulted in a significant improvement in dissipating the energy through the stepped spillway with the addition of appurtenance such as a breaker. On the other hand, comparing the energy dissipation in three different types of breaker conclude that the three-hole breaker gave the maximum result in dissipating the energy. [13]



Fig(5) Configuration of breakers [13]

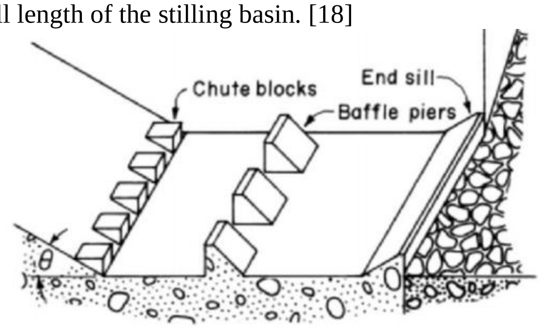
Felder and Chanson [14] conducted an experiment to compare the effect of energy dissipation between uniform step heights and non-uniform step heights. A physical study was conducted with a 5 stepped structure in a steady slope-stepped chute (1V:2H). The rates of energy dissipation for all configurations were calculated in both skimming and transition flow regimes. From the physical study, the author noted that the rate of energy dissipation decrease with an increment of discharge. Nevertheless, there is inequality for all configurations in the terms especially in the dissipation of energy as well as the pattern flow. A little difference in the rate of energy dissipation indicates that the design of stepped spillway with non-uniform step height results in no improvement in terms of dissipation of energy at the end of the chute. [14]

Chen [15] studied the factors influencing the energy dissipation ratio of the stepped spillway. In this study, some main factors that influence the energy dissipation ratio are noted as unit discharge, dam slope, and height of the step. Due to the increment of turbulence kinetic energy occurs during higher unit discharge, the dissipation of energy is shown to be decreased. The author believes that some additive structures should be designed to increase the energy dissipation rate. On the other hand, the smaller dam slope resulted in the increment of energy dissipation ratio. The height of the step influences the energy dissipation ratio differently depending on the unit discharge. The influence of height becomes less with a large amount of discharge and vice versa. The energy dissipation ratio showed a slight increment with the addition in the step height. Thus, the author concludes that the suitable step height should be chosen depending on the unit discharge in the design. [15]

2.3 Hydraulic Jump Type Stilling Basin

Due to its efficiency and simplicity, hydraulic jump type energy dissipator is popular and widely accepted while designing hydraulic structures such as weir, dam, and barrages. [16] In an open channel, the hydraulic jump can be illustrated as a sudden and rapid transition from a supercritical to subcritical flow. It is often used to dissipate the kinetic energy that produces from high velocity of water flows in hydraulic structure. [3] In order to reduce the energy contained in the flow, the stilling basin is necessary to be built as an energy dissipater. [17] To stabilize the jump as well as improving the energy dissipation, additional devices may be introduced to the stilling basin.

According to Alikhani et al [18], designing a stilling basin, chute block, baffle block, and end sill is the device that always be used with a different configuration. Figure 6 shows the location of these appurtenances in the stilling basin. Each of these elements providing a different role to make sure the energy can be optimally dissipated. The first one is chute blocks normally placed into the inclined sections of the spillway. It is a group of concrete blocks that are commonly placed at the head of the stilling basin in order to generate turbulence prior to the hydraulic jump. The second element is the baffle blocks. It is a freestanding concrete block placed in the main basin. Due to the high force, they are subjected to and the potential for cavitation, these blocks are only used for flows below than 20m/s. Finally, the end sills, it is a built-up lip at the tail of the basin, with or without blocks. The height of the end sills has the most significant impact on energy dissipation. Moreover, taller sills a reused in reducing the overall length of the stilling basin. [18]

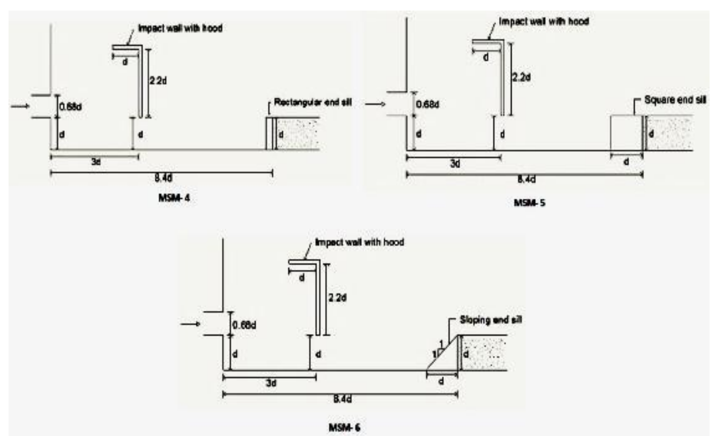


Fig(6) Stilling Basin [1]

Yadav [16] et al studied the design of hydraulic jump type stilling basin for the overflow weir of the canal at Warana dam. By applying Froude's model law, a physical model study is carried out in order to study the percentage of energy dissipator and the location of the jump depending on the amount of discharge flow, the subcritical depth of flow and the initial Froude number. The experiment is conducted in the laboratory considering variable discharge ranging from design charge to around 20% of design discharge. The experiment resulted in stabilizing the condition downstream for the overall flow scenario in the stilling basin. The author concluded that the arrangement of energy dissipation ensures the length of the stilling basin within an acceptable limit. Literally, the stilling basin length is possible to be minimum length to satisfy the location of the jump for varying discharge. [16]

Ashraf [19] conducted an experiment to study the optimum shape of the baffle pier which gave the maximum dissipation of energy. In the experiment, 14 different models of baffle piers were introduced in the flume to have an approximately same pass of water flow and the position of piers is set to be in a fixed position in a row. In this study, it is found that the model with a concave surface able to increase the change of flow direction with low turbulence intensity in recirculation zone downstream baffle piers. Besides, the energy dissipation is higher than the other shape of the model. The author concluded that the vertical semi-circular section dissipating the energy higher than the other model. The author also believes that the right choice of baffle piers is important to have a stable hydraulic condition and shorter stilling basin. [19]

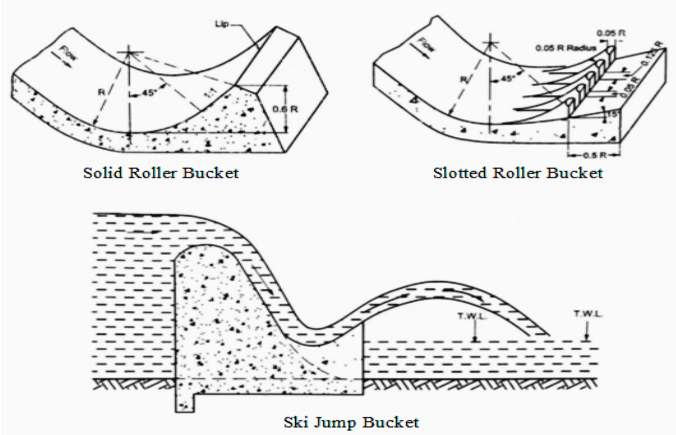
Tiwari et al [20] inspected the energy dissipation by varying the shape of the end sill for the rectangular pipe outlet basin. The author mentioned that the sill plays an imperative role in reducing the length of the stilling basin and helps to enhance the flow pattern downstream of the channel. In the experiment, the 3 shapes of end sill were tested with three Froude numbers values as 1.85, 2.85, and 3.85. Figure 7 shows the shape of the variation of end sill tested in this experiment. It is shown that the shape of the end sill affects the maximum depth of scouring and hence the scour index. During this study, it was found that the sloping end sill (1V:1H) with vertical face upstream improved the dissipation of energy compare to the other end sill. [20]



Fig(7) Variation shape of end sill [20]

2.4 Deflector – Flip Bucket and Ski-Jump Bucket

Nevertheless, in certain cases, it is suitable to direct the discharge water from spillway into the river without pass across the stilling basin. In order to achieve effective energy dissipation, there are several types of deflectors used at the end of the release works of the hydropower project. [21] By constructing a deflector bucket at the toe of the spillway, the water strikes a riverbed can provide a secure distance between dam and spillway. Figure 8 shows the type of deflector that commonly used as a spillway element. The flip bucket (also known as roller bucket) is deflecting the discharge water upwards in order to generate disintegration in the air whereas the jet of a ski jump spillway spill horizontally. [22]



Fig(8) Variation type of deflector [22]

Jian-Hua et al [21] studied the effect of the slotted-flip bucket by varying the width and the angle of the slot. The author conducted the study theoretically and experimentally to estimate the dissipation of energy. Throughout the experiment, it can be noticed that the slot helps the division of water flow, which develops three branches in the right, middle, and the left. The effect of separation becomes greater as the slot angle increase resulting in higher energy dissipation. [21].

In another study, Shantuo et al [23] investigated the hydraulic characteristic of ski-jump-step energy dissipators by conducting an experiment. The study includes the fundamentals and performance of energy dissipation, flow regime, pressure distribution, and the characteristic of the air entrainment. For the stepped chute that having an immense discharge value, the author had introduced a method along with a new approach in dissipating the amount of energy. Figure 9 shows the sketch of the ski-jump-step energy dissipator developed in this experiment. It can be shown in the experiment that the dissipation of energy on a ski-jump-step energy dissipator is said to be greater than the other steps. The author also believes that the design of the aeration basin helps in dissipating the energy with a result of absorption of aeration in ski-jump jet during the development of water cushion. This is due to vortex formation and the impact of the jet flow. Moreover, the aeration basin provokes the preaereted flow, thus improves the performance of flow as well as the dissipation of energy in the stepped chute downstream. The author concluded that the defalcation of energy dissipation in the common stepped chute that having a higher discharge can be improved. [23]

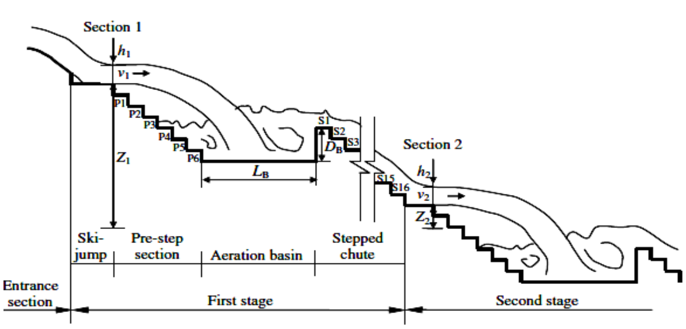


Fig (9) The sketch of ski-jump-step energy dissipator [23]

Heller et al [24] studied the hydraulic of trajectory spillway which focuses on the countenance of the main flow for a 2-D jet where the jet is deflected into the atmosphere with the existence of circular-shaped bucket. An experiment of total of 91 tests was conducted which considering three different radii for the bucket (R= 0.10, 0.25 and 0.4 m). The deflection angles of the bucket were varied to 10, 15, 20, 25, 30 and 40º. The result demonstrates the increase in the rate of energy dissipation when the elevation difference between the tailwater channel and the takeoff point increase. In another hand, the dissipation of energy across a ski jump also observed to improve with the deflection angle and smaller relative bucket curvature. [24]

3. BASIC CONSIDERATION

According to South Dakota Drainage Manual, there are some consideration need to be fulfill in selecting the type of energy dissipator; i) debris control- debris control should be considering the limitation of clean-out access and dissipator should be able to pass the debris, ii) flood frequency-The frequency of flood used in designing energy dissipator should be the same as flood frequency used for the culvert design, iii) ice buildup- the size of dissipator structure should not obstruct the winter low flow and external dissipator may be used if ice buildup is a factor, iv) tailwater relationship- depth of tailwater and maximum velocity for a range of discharge need to be determined by evaluating the hydraulic condition at the downstream, v) cost- considering construction cost, replacement cost, maintenance cost, traffic delay cost and the difficulty of construction, vi) maximum culvert exit velocity- the velocity at the culvert exit should be consistent with the maximum velocity in the natural channel or should be mitigated using energy dissipator or channel stabilization. [25]

4. CONCLUSION

To provide a long term water reserve and protection of flood to our society, dams, and reservoirs are the most effective alternative. The main component for the safety of the dam is the spillways system designed to safely pass the floodwater. At the high velocity of discharged, it is important to protect the downstream area by introducing and selecting the most suitable energy dissipator depending on location, the velocity of flow, and initial Froude Number. During the literature review, it was noted that plenty of work has been carried out by past researchers related to the energy dissipator. Although there are many energy dissipation devices have been designed in conjunction with spillways, outlet works, and canal structures, it is important to make model studies of individual structures to be certain that these will operate as anticipated due to the uncertainty that exists in the repetitive experiment and test regarding the overall performance characteristics of energy dissipators.

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