Available Online at http://www.journalajst.com

ASIAN JOURNAL OF
SCIENCE AND TECHNOLOGY

ISSN: 0976-3376

Asian Journal of Science and Technology
Vol. 5, Issue 6, pp. 369-372, June, 2014

RESEARCH ARTICLE

A CRITICAL STUDY OF HYDRAULIC JUMP IN STILLING BASIN WITH VERTICAL END SILL

***Mubeen Beg**

Department of Civil Engineering, Z.H. College of Engineering & Technology, AMU, Aligarh-202002, U.P., India

ARTICLE INFO

Article History:
Received 30th March, 2014
Received in revised form
03rd April, 2014
Accepted 11th May, 2014
Published online 30th June, 2014

Key words:

Hydraulic jump. vertical,
End sill, Position, length,
Height, Stilling basin

ABSTRACT

Present work deals with a critical study on hydraulic jump in stilling basin with vertical end sill. The objective of present study is to assess the effectiveness of vertical end sill and its position on control of length of stilling basin to economize the cost of stilling basin. The work has been carried out based on reliable data collected from published work of various investigators on hydraulic jump in stilling basin with vertical end sill. The effectiveness of vertical end sill in reducing the length of hydraulic jump (i.e. length of stilling basin) was critically examined from the available data. The study reveals that there is a significant dissipation of energy and reduction in length of hydraulic jump due to the presence of vertical end sill. It has been found that the sequent depth ratio and length of the stilling basin are greatly affected by sill height and position. This study is useful in practical field in the economical design of stilling basin.

INTRODUCTION

A stilling basin is a basin-like hydraulic structure in which all or a part of the energy is dissipated. In a stilling basin, the kinetic energy causes turbulence and it is ultimately lost as heat energy. Kinetic energy of water over the spillway causes severe scouring of downstream river bed and failure of downstream structures. The cshut block and sills with different configurations are used in the stilling basin to dissipate large amount of water energy through formation of a hydraulic jump thereby preventing the failure of hydraulic structures against severe scouring. The stilling basins commonly used for spillways are of the hydraulic jump type, in which dissipation of energy is accomplished by a hydraulic jump. To ensure proper performance and energy dissipation, the stilling basin should be designed to reduce the sequent depth of the hydraulic jump and keep it less than the tail water depth. Otherwise jump will weep out of the basin and downstream scouring will be unavoidable. In a mobile bed made of alluvial materials like clay, silt, sand and gravel, the erosion will be unprecedented leading to collapse of the structure in a very short time. Even where the bed and banks are made of inerodible materials like rock, the high velocity flow causes erosion over a period of time ultimately causing failure of the structure. The turbulent high velocity jet enters into the cracks, fissures, bedding planes and joints of the rock mass subjecting it to constant vibration and dynamic uplift resulting in gradual movement of the rock mass and its failure. It is extremely important; therefore, that excess kinetic energy of flow must be dissipated downstream of the hydraulic structures specially built for the purpose of energy dissipation, commonly known as energy dissipaters. Energy dissipaters must be efficient enough so that the flow downstream of the energy dissipaters is tranquil and don't contain any excess energy of flow. The stilling basins commonly used for spillways are of the hydraulic jump type. A hydraulic jump can be stabilized in stilling basin by using appurtenances or accessories such as chute blocks, basin blocks and end sill. A hydraulic jump can be stabilized in stilling basin by using appurtenances or accessories such as chute blocks, basin blocks and end sill. Height of sill, position and configuration have considerable effect on the jump and dissipation of water energy.

Types of Energy Dissipaters

There are several types of energy dissipaters. Selection of particular type of energy dissipater depends upon the amount of energy to be dissipated and erosion control required downstream of a structure. It is governed by inflow Froude number (Fr_1), available tail water depth (y_2) and nature of bed and bank materials. One or more of the following methods achieves the reduction in velocity. Reduction in velocity can be achieved by allowing the free failing jet to strike the rocky surface directly; reversing direction of free falling jet into the air, by impact of one jet against other, by striking the flow in such a way that rollers are formed and presently considered method of creation of hydraulic jump. Although there is no hard and fast rule to select a particular type of energy dissipater, but following factors are considered while selecting the type of energy dissipater:

i) Type of dam and its spillway
ii) Frequency and intensity of flood flows.

****Corresponding author: Mubeen Beg***
Department of Civil Engineering, Z.H. College of Engineering & Technology, AMU, Aligarh-202002, U.P., India

iii) The degree of protection to be provided for very high floods.
iv) Proximity of power house, tailrace and other structure.
v) Velocity and nature of flow.
vi) Elevation of tail water at various discharges.
vii) Nature of foundations.
viii) Type and amount of bed material rolling on the spillway.
viii) Safety of existing structure downstream.

These factors only give broad guidelines to select a suitable type of energy dissipater, which is subjected to model study. The final choice can be made after satisfactory model studies
A hydraulic jump type-stilling basin may be defined as a dissipater in which whole or part of a hydraulic jump is confined. In this type of basins, the energy is dissipated by formation of hydraulic jump within the basin. The stilling basin employs the hydraulic jump for energy dissipation and is the most effective method of dissipating energy in flow over spillways.

Stilling Basins

A stilling basin is a basin-like structure in which all or a part of the energy is dissipated. In a stilling basin, the kinetic energy causes turbulence and it is ultimately lost as heat energy. The stilling basins commonly used for spillways are of the hydraulic jump type, in which dissipation of energy is accomplished by a hydraulic jump. A hydraulic jump can be stabilized in stilling basin by using appurtenances or accessories such as chute blocks, basin blocks and end sill.

End Sill

It is constructed at the downstream end of the stilling basin. It may be solid or dentated. Its function is to reduce the length of the hydraulic jump and to control scour. For large basins designed for high incoming velocities, the sill is usually dentated to perform an additional function of diffusing the residual portion of the high velocity jet that may reach the end of the basin. In a dentated sill, there are teeth with small gaps which diffuse the jet. These gaps and the projections between them look like human teeth.

Use of Hydraulic Jump As Energy Dissipater

From a practical view point, hydraulic jump is a useful means of dissipating excess energy in supercritical flow. Its merit is in preventing possible erosion below overflow spillways, chutes and sluice, for it quickly reduces the velocity of the flow on a paved apron to point where the flow becomes in capable of scouring the downstream channel bed. The hydraulic jump used for energy dissipation is usually confined partly or entirely to a channel reach that is known a stilling basin. Present work deals with a study on hydraulic jump in stilling basin with vertical end sill. The objective of present study is to assess the effectiveness of vertical end sill in reducing the length of hydraulic jump (i.e. length of stilling basin) to economize the cost of stilling basin The task was accomplished by processing and analyzing the reliable data collected from published work of various investigators on height and location of vertical end sill.

Studies on Energy Dissipation Using Vertical End Sill

Stilling basins are usually necessary energy dissipaters in conjunction with outlet works, spillways and regulating structures. Determining the amount of energy absorption and estimating the velocity values and its fluctuations, especially near the bed, is essential for the bed protection stability analysis. Any excessive scouring in the river bed downstream the stilling basin can eventually result in the failure of the hydraulic structure. The hydraulic jump taking place on a stilling basin is often categorized into four different forms according to the Froude number of the upstream jet. An undular jump with very low energy dissipation is associated with Froude numbers ranging between 1.0 to 1.7. A weak jump is associated with Froude numbers ranging between 1.7 to 2.5, with low energy dissipation up to 20%. An oscillating jump is associated with Froude numbers ranging between 2.5 and 4.5, with a very rough water surface and very pulsating features and usually seen with low head structures. Turbulence oscillates from the bottom to the surface instantaneously. These oscillations generate very large waves of irregular period which can travel for long distances downstream the stilling basin. A steady or stable jump is associated with Froude numbers ranging between 4.5 to 9.0, with high energy dissipation of about 45% to 75%. For Froude numbers higher than 9.0 the jump is stable but rough water surface can prevail. Stilling basins with dented or continuous sills are frequently used as energy dissipaters downstream of hydraulic structures. several investigators have carried out work on the use of end sill for energy dissipation.

Hager (1992) classified the jump over a vertical sill into A-jump, B-jump, minimum B-jump, C-jump and D-jump. The A-jump is classical hydraulic jump which is characterized by the maximum sequent depth ratio (where sill is far away to affect the jump). By decreasing the tailwater depth, toe of jump moves toward the sill and a B-jump occurs in which the flow is considerably modified by sill and the streamline pattern becomes curved over sill. Also the height of bottom rollers grows and a surface boil appears at the rear sill side, yet without significantly changing the free surface profile. As the tailwater depth decreases more, the distance between the toe of the jump and upstream sill face is further reduced and the curved flow pattern over the sill is amplified. Moreover, the surface current starts to plunge behind the sill, yet without reaching the channel bottom. A further characteristic of such flow, referred to as minimum B-jump, is the formation of a second roller at the downstream sill zone and a C-jump is characterized by having the maximum difference between the depth of flow over the sill and the tailwater depth. D-jump initiates when flow is disturbed more and roller waves can reach the bed and scouring becomes expectable. When tailwater depth is low, D-jump may appear sooner than normal conditions. Noshi H.M., Romish, K. et al., (1998) reported that for the case of steady jump, the end-sill reduces the maximum velocity values near the bed to about 0.40 times its corresponding value if no end-sill is constructed. For the case of oscillating jump, the end-sill reduces the maximum velocity values near the bed to also about 0.40 times its corresponding value if no end-sill is constructed. For the case of weak jump, the end-sill reduces the maximum velocity values near the bed to also about 0.40 times its corresponding value if no end-sill is constructed. For the case of undular jump, the end-sill reduces the maximum velocity values near the bed to also about 0.30 times its value if no end-sill is constructed. The different heights of end-sill resulted in approximately equal energy dissipation effect. The smallest end-sill height used of about 0.15 times the tail water depth is therefore found to be sufficient to improve the energy dissipation near the bed. This indicates that increasing the height of the end sill above that sufficient height does not improve the energy dissipation efficiency any further. V. I. Bukreev (2002) presents the experimental data on typical profiles of free surface and channel bottom pressure for a supercritical over a sill. This flow is shown to have, along with the known critical depth, two other characteristic depths, one of which is at the channel exit to the atmosphere and the other determines conditions under which the disturbances propagate well upstream of the sill. The experimental data are compared with calculation results based on a mathematical model that incorporates turbulent mixing upon wave breaking. Rand (1965) presented his work describing flow over a vertical sill in an open channel. The author emphasized that practical engineering applications are handicapped if either the relationship between the recommended design and the physical appearance of the flow is not comprehended or if one cannot predict the changes in the flow pattern of design modification.

Position of Hydraulic Jump

The hydraulic jump can be controlled with a terminal thin-crested sill of relative height S as it is shown in Fig. 1. As usual, Ls denotes the distance between the toe and the upstream sill face, Lj is the length of the jump, h_1 and h_2 are the flow depths in the approaching and the tailwater regions.

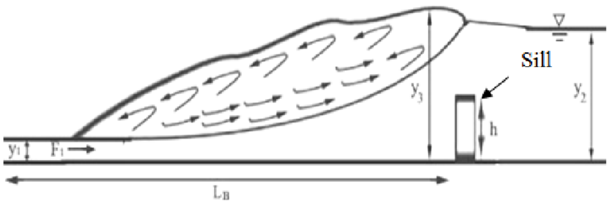

Fig. 1. Forced hydraulic jump in stilling basin with a continuous sill

When the relative length Lj/L_B (where, Lj=length of the hydraulic jump and L_B= length of stilling basin) is greater or at least equal to unity, the hydraulic jump is completely located on the apron downstream from the sill beyond which the flow is supercritical. Otherwise, the flow over the sill is free and the energy dissipation is not accomplished. The increase of the inflow Froude number F_1 due to the increase of the discharge Q or the decrease of the inflow depth h_1 moves the jump upstream and the A-jump formation happens when the end of the roller is just above the front face of the sill. At the same time, an increase of the distance *x*o can be observed (Fig. 1.1). Increasing tail-water by adding a second sill at the channel extremity and increasing simultaneously the inflow Froude number, the so-called minimum B-jump is thus formed (Fig. 1.1). This is a forced jump, characterized by: a main roller of length L_R, a bottom roller of length L_{RB} beyond the sill and the formation of a second surface roller. Thus, one may write the length of the basin as $L_B = (L_S + L_{RB})$, where, . L_B=length of Basin and L_{RB}=length of bottom roller)

Analysis of Researches on Use of Sill To Control Hydraulic Jump

A.Alikhani et. al. (2010) has reported that the use of the end-sill is a common practice to reduce the jump length and confine it on the stilling basin. They said that stilling basins with dentate or continuous sills are frequently used as energy dissipaters downstream of hydraulic structures. They conducted experiments to evaluate effects of a single vertical continuous sill and its position on control of depth and length of a forced jump in stilling basin without considering tail water depth which is variable and totally controlled by downstream river conditions. A sill with five different heights was placed at three different longitudinal distances along a scaled model of a stilling basin. The hydraulic characteristics of the jump were measured and compared with the classical hydraulic jump under variable discharges. Results of experiments confirmed significant effect of the sill on dissipation of energy. The effect of the introduction of the end-sill on the energy dissipation efficiency near the bed is presented in this study. The effect of the end-sill dimensions on the efficiency of energy dissipation is also presented for the four types of hydraulic jumps. It is shown that using an end-sill height of about 0.15 the tail water depth presents a sufficient height that can improve the energy dissipation, for the range of flow conditions investigated. It is also shown that increasing the end-sill height than this sufficient height does not improve the energy dissipation any further.

The study presented an estimate for the near-bed maximum velocity values downstream stilling basins with and without end-sill. These values are considered useful especially for determining the size of bed protection material downstream the stilling basin. The introduction of a sufficiently high end-sill is shown to reduce the downstream near bed velocity values to about 0.30 for the undular jump and 0.40 for the other types of hydraulic jump. Moreover, the maximum near-bed velocity values downstream the end-sill is shown to be about 2, 3, 6 and 2 times its corresponding free stream values for the steady, oscillating, and weak and undular jump, respectively. The information presented in the study is thought to be a very useful design tool to best optimize the end-sill dimensions and to determine the size of bed protection material and its extension downstream the stilling basin. As stated by Abdel-Azim M. Negm (2002), scour downstream of hydraulic structures may endanger the safety of the structures if the necessary precautions are not considered during the design stage.

Normally, different measures produce different effects on reducing the maximum scour depth of hydraulic structure. In this paper, the effects of different arrangements of sills inside an abruptly enlarged stilling basin will be discussed. An experimental program was conducted to investigate the effects of continuous end sill, one asymmetric side sills, double staggered asymmetric side sills, symmetric side sills, central sill and continuous central sill. The flow patterns were observed and the maximum scour depths were recorded. The results revealed that in most of the cases the flow patterns are asymmetric resulting in asymmetric scours. The reduction in the maximum scour depth depends on the type of arrangement of the used sill and on the flow conditions represented by Froude number. Both of the central sill with limited width and continuous central sill improved the flow patterns towards symmetric type and yielded minimized maximum scour depth with preference to the continuous sill. A literature review reveals that hydraulic jumps were systematically investigated in rectangular channel. Among other studies, those of Forster and Skrinde (1950) and of Hager and Li (1992) relate to the controlled jump, and the study of Bretz (1988) for the forced jump

RESULTS AND DISCUSSION

To ensure proper performance and energy dissipation, the basin should be designed to reduce the sequent depth of the hydraulic jump and keep it less than the tail-water depth. Otherwise jump will weep out of the basin and downstream scouring will be unavoidable. To reduce the sequent depth particularly where the tail-water depth is too small (normally where downstream of the structure is steep), a continuous sill can control and stabilize the jump, thus reducing the basin length. Sill height, position and configuration (where more than one sill is used) have considerable impact on the jump and dissipation of water energy. The results presented by Abdel-Azim M. Negm (2002), revealed that in most of the cases the flow patterns are asymmetric resulting in asymmetric scours. The reduction in the maximum scour depth depends on the type of arrangement of the used sill and on the flow conditions represented by Froude number. Both of the central sill with limited width and continuous central sill improved the flow patterns towards symmetric type and yielded minimized maximum scour depth with preference to the continuous sill. Sudden expanding stilling basins may be used effectively in dissipating the energy downstream the hydraulic structures.

As reported by Noshi H.M., Romish, K. et al., (1998), stilling basins are often used for energy dissipation in conjunction with spillways, outlet works and regulating structures. The effect of the end-sill dimensions on the efficiency of energy dissipation is presented for a wide range of upstream jet flow intensity conditions. The study of Hani M.Noshi (1998) presents an estimate for the near-bed maximum velocity values downstream stilling basins with and without an end-sill. These values are useful for determining the size of bed protection material. The high turbulence intensity in the recirculation zone downstream the end-sill results in an unstable hydraulic conditions. The maximum expected near-bed velocity values in the recirculation zone are essential for the selection of size of bed protection material. Patrick F. Cummins (2010) reports that in stratified tidal flow over a sill, the character of the upstream response is determined by a Froude umber Fr based on the stratification near the surface.

This is distinguished from the Froude number governing the response in the neighborhood of the sill crest, which is based on the weak density step associated with a flow bifurcation. For overate values of Fr, the upstream response consists of nonlinear avers or a weak undular bore. For larger values of Fr, a strong, quasi-stationary, internal hydraulic jump dominates the upstream response. At sufficiently large a value of Fr, the upstream bore is swept own stream and lost. Acoustic backscatter and velocity data are presented for the case of strong internal bore or gravity current in a tidally modulated sill flow. Numerical simulations with varying near-surface stratification re presented to illustrate the upstream responses at different values of Fr. Zhiqun Deng (2007) carried out research at Dalles Dam on the Columbia River, where fish are believed to sustain injury from exposure to turbulence and from collisions with baffle blocks and end sills in the stilling basin at high spillway discharges. Because taking velocity measurements would be exceedingly difficult in this environment, a system of pressure transducers was installed to record high-frequency pressure data for a range of spillway discharges. The sensors were mounted below two of the spillways on the tops, faces, and sides of baffle blocks; in the gaps between baffle blocks; and on the top and face of the end sill.

Conclusion

Critical review of literature survey reveals that the work on vertical end sill for controlling the hydraulic jump in the stilling basin carried out by Alikhani et al (2010) is quite significant. Considerable effect of sill height and position in reduction of the sequent depth and length of the stilling basin is found. Thus, proper designs of the sill height and its location have significant contribution to cost effectiveness of a stilling basin. Design criteria proposed by Alikhani et al (2010) is basically developed for B-jump with inflow Froude numbers F_1 = 4-12 and h/y_1 = 2 to 8. However, an over design of sill height to about 20% and 30% will facilitate it for C-jump and D-jump respectively. The advantage of the proposed method is its simplicity in practice and its capability to estimate sill height and basin length for most flow type without considering tail water depth which is controlled by slope and river conditions downstream of the basin. Present study reveals that a vertical end sill has a significant effect on shortening the length of hydraulic jump. The shortened length of hydraulic jump is, in fact, cost effective in the construction of stilling basin in dam spillways.

REFERENCES

Hager, W.H., (1992). Discussion of Force on Slab beneath Hydraulic Jump, Journal of Hydraulic Engineering, ASCE, vol. 118, No. 4, pp. 666-668,

A. Alikhani, R. Behrozi-Rad and, M. Fathi-Moghadam (2010). Hydraulic jump in stilling basin with vertical end sill" International Journal of Physical Sciences Vol. 5 (1), pp. 025-029.

Noshi H.M., Romish, K. et al., (1998), “Sluiceway Detail Model”, Report, Hydraulics Research Institute, Delta Barrge 13621, Egypt.

V. I. Bukreev (2002). “Super critical flow over a sill in an open channel”, Journal of applied mechanics and technical physics, vol. 43, No.6, pp. 830-835.

Zhiqun Deng, (2007) Journal of Hydraulic Research Vol. 45, No.5,pp.674- 678

Negm, A.M., Abdel-Aal, G.M. Saleh, O.K, & Sauida, M.F. (2002), “Effect of supercritical flow on scour characteristics downstream of sudden expanding stilling basins”, Egyptian Journal for Engineering Science and technology EJEST,Vol.6,pp.1-13

Deng Z, Guensch GR, Richmond MC, Weiland MA, Carson TJ (2007).Prototype measurements of pressure fluctuations in The Dalle stilling basin, J. of Hydraul. Res. 45(5): 674–678

Rand, W., 1965 "Flow Over A Vertical Sill in An Open Channel", Journal of Hydraulic Division, ASCE, vol. 91, No. 4, pp. 97-121,.

Patrick F., Laurence Armi, 2010: Upstream Internal Jumps in Stratified Sill Flow: Observations of Formation, Evolution, and Release. J. Phys. Oceanogr., 40, 1419–1426.

****