



Hydraulic jump control using stilling basin with Adverse slope and positive step

S.K. Mazumder

To cite this article: S.K. Mazumder (2020): Hydraulic jump control using stilling basin with Adverse slope and positive step, ISH Journal of Hydraulic Engineering, DOI: [10.1080/09715010.2020.1824131](https://doi.org/10.1080/09715010.2020.1824131)

To link to this article: <https://doi.org/10.1080/09715010.2020.1824131>



Published online: 20 Sep 2020.



Submit your article to this journal [↗](#)



View related articles [↗](#)



View Crossmark data [↗](#)



Hydraulic jump control using stilling basin with Adverse slope and positive step

S.K. Mazumder

Civil Engg, Delhi Technology University (Former Delhi College of Engg, Delhi)

ARTICLE HISTORY Received 10 September 2020; Accepted 12 September 2020

KEYWORDS Jump; basin; efficiency; slope

The paper deals with hydraulic jump characteristics in a stilling basin (called basin hereafter) provided with an adverse slope and a positive step at the end of the basin. Different characteristics of hydraulic jump, studied both analytically and experimentally, include (i) conjugate depth relation (D_2/D_1) (ii) lengths of roller (L_r) (iii) jump length (L_j) and (iv) relative loss of energy ($\Delta E/E_1$) in the jump within the basin. Studies were made for four different slopes (0; 0.01; 0.03 and 0.05) combined with three positive steps of heights (0; 3 cm and 5 cm.). In total, 144 experiments were performed with inflow Froude's no. (F_1) varying from 4 to 10. It is concluded that the sequent depth ratio, jump length and roller length reduce with increase in slope and height of positive step by 20%, 39.3% and 32.6%, respectively, as compared to those in a classical jump on level floor. Relative energy loss increased with rise in slope and step height by 13% more than that in a classical jump. Fig. 7(a) and 7(b) illustrate the variation of the above jump characteristics with slope and step height, compared to ones in classical jump. Fig. 8(a) and 8(b) indicate the variation of relative energy loss ($\Delta E/E_1$) and jump efficiency (η) respectively with pre-jump Froude's number (F_1) for different slopes and step heights. Values of $\Delta E/E_1$ and η are compared with those in a classical jump on level floor. Authors are, however, silent about how to decide the slope and step height combined together for best performance of stilling basin operated under different F_1 -values corresponding to different flows. Too high step may cause flow choking and jump submergence and too low step may result in repelled jump. In case tail water depth is less than sequent depth, Ranga Raju (1993) plotted relation between F_1 and D_2/D_1 for different values of positive step height such that the hydraulic jump ends at the step in a stilling basin of length $5(D_2+\Delta Z)$ where ΔZ is the height of positive step. Earlier a similar paper on 'Characteristics of hydraulic jump on rough bed with adverse slope' (Parsamehr et al. 2017) was published in ISH J. of Hyd. Engg. and discussed by Mazumder (2017). Discusser (Mazumder and Naresh 1988) performed a series of experiments to find hydraulic jump characteristics with both horizontal floor, as well as floor with adverse slope. Variation of conjugate depth, length of jump, roller length and relative energy loss were plotted against pre-jump Froude's no. of flow (F_1) for different slopes. Results obtained were almost similar to the ones found by the authors of the paper. Use of chute blocks, baffle blocks and end sill has been prescribed by Bradley and Peterka (1957) for reducing length and conjugate depth and for improving the efficiency of USBR type stilling basins (1968). SAF basin was developed in St. Anthony Falls

Hydraulics Laboratory in USA. Depending upon the pre-jump Froude's number of flow (F_1), several types of stilling basins were developed by USBR (1968).

Stilling basin – an integral part of dams and barrages and other hydraulic structures – is provided to dissipate the differential energy (ΔE), i.e. the difference of energy levels between the entry of a basin and tail channel downstream of the basin as shown in Figure 1. It is presumed that the differential energy (ΔE) is completely dissipated within the basin due to hydraulic jump formation within the basin. Basin length usually varies from 4 to 6 times the conjugate depth (D_2) depending upon inflow pre-jump Froude's number (F_1). It is well established that the jump is steady and perfect only when F_1 is greater than 4.5 as in high dams. In many of the low height hydraulic structures, e.g. barrages, canal drops, regulators, etc., F_1 is found to be less than 4.5. Since authors have studied jump characteristics and energy loss for $4 < F_1 < 10$, the results may not be applicable in such situations. For example, inflow F_1 – values at design flood discharge in Farakka and Kosi barrages in India are $F_1 = 2.8$ and $F_1 = 3.4$, respectively. In these low height dams/barrages, drops, regulators, etc., the jump is not perfect as the basin efficiency is poor and hence considerable amount of residual kinetic energy leaves the basin as shown in Figure 1.

From Figs.7 and 8 in the paper, it is observed that both $\Delta E/E_1$ and η -values decrease with reduction in F_1 -values. Efficiency of a stilling basin (as energy dissipater) is different from hydraulic jump efficiency. Referring to Figure 1, if the actual energy dissipated within the basin is $\Delta E'$ and the differential energy required to be dissipated is (ΔE), the residual kinetic energy of flow leaving the basin is ($\Delta E - \Delta E'$). As the tail water depth D_2 after the basin remains the same, the only way the residual energy can be contained by the flow with same depth (D_2) and same mean velocity of flow (V_2) is through non-uniformity of velocity distribution as indicated in Figure 2(a) and 2(b).

Coriolis' coefficient (α) is an index by which non-uniformity of velocity can be expressed as

$$\alpha = [1/(AV^3)] \int u^3 dA \quad (1)$$

where u is the local velocity normal to an elementary area dA , A is the sectional area of flow and V is the mean velocity through the sectional area A . It may be noted that when $u = V$, i.e. for uniform distribution of velocity, $\alpha = 1$. Greater the non-uniformity, higher is the value of α_2 (Figure 2). At the exit of the basin, the value of α ($=\alpha_2$) will

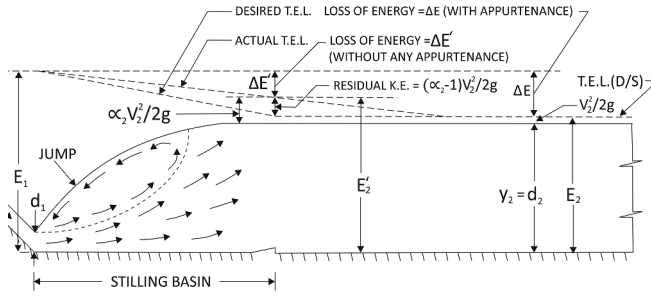


Figure 1. Showing hydraulic jump, Total Energy Line (TEL) and residual kinetic energy ($\Delta E - \Delta E'$).

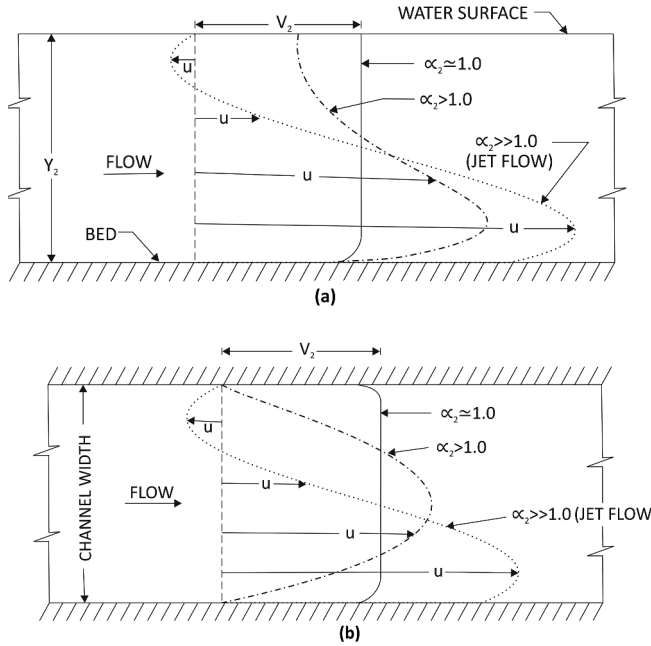


Figure 2. Showing distortion of flow velocity in A channel D/S of basin due to residual kinetic energy (a) Along depth and (b) Along width.

be greater than unity whenever there is residual energy in the flow leaving the basin. Since the flow depth after the basin is constant, the residual kinetic energy of flow can be expressed as

$$(\Delta E - \Delta E') = (\alpha_2 - 1)V_2^2/2g \quad (2)$$

where V_2 is the mean velocity of flow and α_2 is the Coriolis' coefficient at the basin end which can be expressed as

$$\alpha_2 = [1/(A_2 V_2^3)] \int u^3 dA \quad (3)$$

where A_2 and V_2 are the sectional area and mean velocity of flow at the basin end, respectively.

Defining efficiency of a basin as energy dissipator

$$\eta = \Delta E' / \Delta E \quad (4)$$

or,

$$1 - \eta = 1 - (\Delta E' / \Delta E) = (\Delta E - \Delta E') / \Delta E = [(\alpha_2 - 1)V_2^2/2g] / \Delta E \quad (5)$$

or,

$$\eta = 1 - [(\alpha_2 - 1)V_2^2/2g] / \Delta E \quad (6)$$

Equation (6) shows that $\eta = 1$ (i.e. basin efficiency is 100%) when $\alpha_2 = 1$. Higher the α_2 value more is the residual kinetic

energy, lower is the basin efficiency and greater will be the non-uniformity of flow and scour downstream, especially where the bed and bank consist of fine materials like silt and sand.

Figure 3 is a plot of η against α_2 for different discharges (Q) obtained by the discussor experimentally (Mazumder and Naresh 1988). It may be seen that when the residual energy is 1%, i.e. $\eta = 99\%$, α_2 values are about 3, 4 and 7 for Q -values of 31, 15.5 and 7.75 LPS, respectively. With 2% residual energy (i.e. $\eta = 98\%$), respective values of α_2 are about 4, 6 and 12 which indicate very high degree of non-uniformity of flow (Figure 2) leaving the basin and causing scour downstream. It may be noted that in sub-critical flow, kinetic energy of flow is very low compared to flow depth and hence even a small amount of residual kinetic energy of flow causes a high degree of non-uniformity of flow responsible for scour and erosion downstream.

Discussor (Mazumder 1994; Mazumder and Sharma 1983) developed an innovative method of improving basin performance by providing adverse slope (β) to the floor of basin with straight diverging sidewalls. β Value was derived (Equation 7) such that the axial components of sidewall reactions acting in the flow direction are neutralised by the axial component of bed reaction acting against the flow direction.

$$\beta = \tan^{-1} [(d_1^2 + d_2^2 + d_1 d_2) \tan \phi / (bd_2 + Bd_1 + 2Bd_2 + 2bd_1)] \quad (7)$$

where b and B are half widths of basin, d_1 and d_2 are pre-jump and post-jump depths at the entry and exit of the basin respectively; ϕ is the angle of divergence of the side walls as

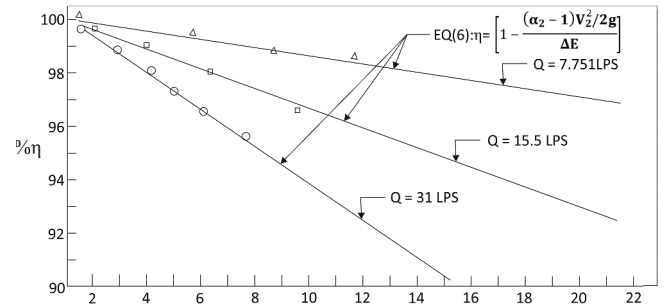


Figure 3. Showing interrelation between η and α_2 .

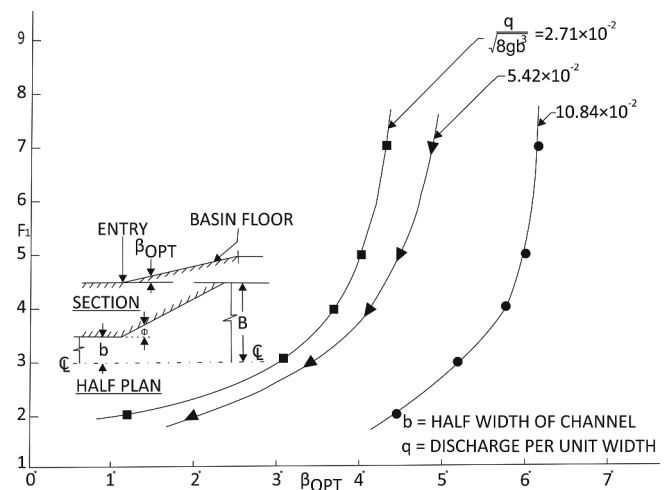


Figure 4. Showing optimum adverse slope of basin floor (β_{opt}) for different prejump froude no. $F_{r1}(=F_1)$ and discharge intensity ($q = Q/2b$).

shown in Figure 4. Experiments were conducted and the performance of the basin was measured with and without basin floor slope (β). Optimum values of slope ($\beta_{opt.}$) for best performance of the basin are given in Figure 4. With level floor ($\beta = 0^\circ$), the performance of the basin measured in terms of η and α_2 was extremely poor. With adverse slope ($\beta = \beta_{opt.}$), performance improved remarkably and the computed values of η and α_2 were found to be almost equal to unity indicating that there was hardly any residual kinetic energy of flow leaving the basin (Mazumder, 2020).

Scour downstream of a stilling basin in weirs and barrages is primarily due to the inefficient stilling basin performance which in turn is dependent on the nature of hydraulic jump formed within the basin and the energy dissipation that actually occurs within the basin. A part of the pre-jump energy (E_1 in Figure 1) is converted to pressure energy as the depth increases from d_1 to d_2 as shown in Figure 1. The remaining energy (mostly kinetic energy, since d_1 is very small compared to $V_1^2/2g$), transferred to turbulent flow field, can not be recovered and is commonly known as head loss in jump. Chaturvedi (1963) measured turbulent quantities in a conical diffuser and found the head losses in terms of the turbulence parameters (u' , v' and w'). Production of turbulence in hydraulic jump is dependent upon the nature of impact (Hinze 1959) between the incoming super-critical flow and outgoing sub-critical flow. When $F_{r1} < 4.5$, strength of impact is poor resulting in low turbulence production giving rise to residual kinetic energy of flow leaving the basin.

Basin efficiency as an energy dissipater is also governed by the skewness of jump front. Model study (Lofty et al. 2020) was carried out to investigate scour downstream of several barrages on river Nyle in Egypt due to asymmetric operation of gates. Non-dimensional scour depths, d_s/a_g (where d_s is scour depth and a_g is gate opening) were measured in 80 experiments performed with different gate operation schedule – both symmetric and asymmetric – to investigate the effect of several parameters, e.g. pre-jump Froude's number (F_{r1}), jump submergence (S_j), variation of head (h) and expansion ratio (e) on the scour downstream of the barrage gates. While the effect of other parameters on jump performance is established (Rajaratnam 1965; USBR 1968; Peterka, 1958; Chow 1973; Hager 1992), the effect of expansion ratio (e) on jump performance and scour due to asymmetric operation of gates was investigated first time by Ahmed. Expressing e as the ratio of gate width in operation to the total width of the channel, authors found that the scour depth increased significantly due to partial and asymmetric operation of gates. Scour depth $d_s/a_g = 0.24$ with $e = 1.21$ when all the five gates were opened. Scour depth $d_s/a_g = 2.76$ with $e = 6.12$ when only one side gate was open showing an

unprecedented increase in scour by 1050%.

Disclosure statement

No potential conflict of interest was reported by the author.

References

- Bradley, J.N., and Peterka, A.J. (1957) "Hydraulic design of stilling basins-stilling basins with sloping apron (Basin-V)", Proc. ASCE, J. of Hydraulics Division, 83 (HY-5), Paper no. 1405, p.1-32; Discussions 1958, 84 (HY2), Paper no. 1616, p. 41-56; 1958; 84 (HY-2), paper no. 1616, p.59-75; 1958, (HY-5), paper no. 1832, p.71; 1958, 84 (HY-5), paper no. 1832, p.77-81.
- Chaturvedi, M.C. (1963). "Flow characteristics in axis-symmetric expansion." *JHE, ASCE*, 1999, 61-92.
- Chow, V. (1973). *Open Channel Hydraulics*, International Student. McGraw-Hill International Book Co., Singapore.
- Hager, W.H. (1992). *Energy dissipaters and hydraulic jump*, Kluwer Academic Publishers, London, 5.
- Hinze, O. (1959). *Turbulence*, McGraw-Hill, New York, USA.
- Lofty, A.M., Basiouny, M.E., Abdelhaleem, F.S., and Nasrallah, T.N. (2020, Jan). "Scour Downstream of Submerged Parallel Radial Gates." *J. Water Energy Int.*, Central Board of Irrigation & Power Malcha Marg, Chanakyapuri, New Delhi'. Vol. 62, 50-56.
- Mazumder, S.K. (1994, March) "Stilling basin with rapidly diverging side walls for flumed hydraulic structures" Proc.National Symposium on Recent Trends in Design of Hydraulic Structures (NASORT DHS-94) org. by Deptt. Of Civil Engg. & Indian Soc. For Hydraulics, Univ. of Roorkee (now IIT, Roorkee), University of Roorkee (now IIT Roorkee), India.
- Mazumder, S.K. (2017). "Discussions on the paper 'Characteristics of hydraulic jump on rough bed with adverse slope', by Parastoo Parsamehr et al." *ISH J. Hyd. Engg.* Published online: 3 Aug 2017. Vol. 24, 345-348.
- Mazumder, S.K. (2020). Flow transition design in hydraulic structures, Pub. By CRC Press, Taylor & Francis Group, New York, NY, 10017, Chapter-4. 139-142.
- Mazumder, S.K., and Naresh, H.S. (1988). "Use of appurtenances for efficient design of Jump type dissipaters having diverging side walls for flumed canal falls." *J. Civil Eng. Div. The Inst. Of Engrs (I)*, 68(pt C16, May), 284-290.
- Mazumder, S.K., and Sharma, A. (1983) "Stilling Basin with diverging side-walls" Proc. XX, IAHR CONGRESS, Vol. 7, Moscow, Sept 5-7
- Parsamehr, P., Farsadzadeh, D., HosseinzadehDalir, A., Abbaspour, A., and Esfahani, M.J.N. (2017). "Characteristics of hydraulic jump on rough bed with adverse slope." *ISH J. Hyd. Engg.*, Pub. online on 17 April, 2017. 23, 301-307. doi:10.1080/09715010.2017.1313143
- Peterka, A.J. (1958). *Hydraulic design of stilling basins and energy dissipaters*, US Deptt. of Interior, Bureau of Reclamation, Engg. Monograph, 25, Denver, Colorado, USA.
- Rajaratnam, N. (1965). "Submerged hydraulic jump." *Proc. ASCE, JHE*. 91 (HY4), 71-96. Discussions:1966,92(HY-1), pp.146-155; 92 (HY2), pp.420-421; 92(HY4),pp.154-156; 92(HY6),pp.207,1967,93(HY(3))PP.179.
- Ranga Raju, K.G. (1993). *Flow Through Open Channels*, Tata McGraw-Hill Pub.Co.Ltd., New Delhi.
- USBR. (1968). *Design of Small Dams*, Oxford & IBH Publishing Co., New Delhi.