Discussion on Paper

Scour Downstream of Submerged Parallel Radial Gates

(Published in January 2020 issue of the Water and Energy International)

S.K. MAZUMDER

Former AICTE Prof. Emeritus, Delhi Technology University (Former Delhi College of Engg.)

Authors are congratulated for their paper dealing with investigations of scour downstream of barrage gates in river Nile in Egypt. Similar scour were observed in barrages in India too. Discussor had the opportunity to investigate scour in Farakka barrage on river Ganges and Kosi barrage on river Kosi in India (Mazumder, 2011). Uncontrolled scour and erosion of river bed and banks often result in breaches, meandering and sometimes flow avulsion. Often the safety of barrage itself is threatened due to outflanking.

The main cause of scour downstream of barrages is inadequate energy dissipation in the stilling basin (called basin hereafter) invariably provided downstream of the barrage gates. In all barrages and weirs, there is always flow choking resulting in rise in energy level and afflux upstream of the barrage. The excess energy of flow (ΔE as shown in Fig.1 in this discussion paper) above the normal energy level (in pre -barrage state) must be completely dissipated within the basin before the flow moves downstream over natural river bed made of very fine alluvial soil in rivers like Nile and Ganges

In the classical design of the basin , it is presumed that the excesses energy (ΔE) is completely dissipated within the basin and the energy of water flowing downstream of the basin will be equal to the normal energy of flow (E_2) corresponding to normal flow velocity (V_2) at normal tail water depth of flow ($y_t = d_2$ in Fig. 1). The basin length provided (Fig. 1 in the paper by author) is 150 cm which seems to be more than the length of jump. It is assumed the the basin length is adequate to contain the jump fully. Authors have not mentioned about the basin type adopted as there is no data available for computing pre- jump Froude's Numbers of flow (Fr_1) which is found to vary from 2.5 to 8.5 (Figs. 3 to 9 in the paper) for different values of expansion ratio (e), head variation (h) and jump submergence (S_j) .

It is well established (Hager, 1992; Peterka,1958) that the jump becomes steady only when $Fr_1 > 4.5$. In most of the barrages in India, pre-jump Fr_1 is found to vary between 2 to 4 - a range in which jump is not perfect. In undular jump ($1<Fr_1<1.7$), weak jump ($1.7<Fr_1<2.5$) and oscillating jump ($2.5<Fr1<4.5$), energy dissipation is incomplete as the jump is not perfect

Effect of submergence on energy dissipation is well established (Chow, 1973); but the effect of expansion ratio, e (defined as the ratio between gate opening and channel width) is investigated by the authors for the first time in the paper. Average scour depth (ds/ag) is found to increase with expansion ratio (e). d_s/a_g =0.24 when e=1.21 (for all gates open) compared to d_s/a_g=2.76 when e=6.12 (one side gate open)- an unprecedented increase of scour by 1050%. In Fig.1 in the paper, authors gave only a qualitative description of of scour depth (d_s) and its location (l_m). Value of the paper would have further increased if the authors had given the details of scour depths and their locations with respect to the different schedule of gate opening.

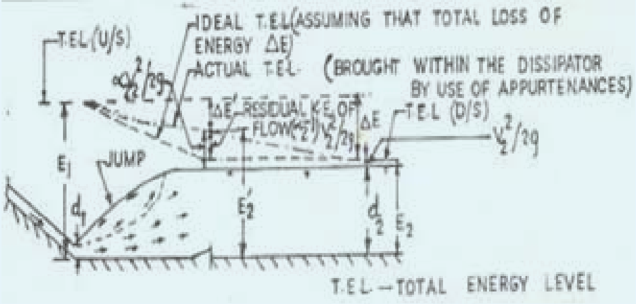

Fig. 1 : Showing Jump , Energy line and Residual Kinetic Energy : $\Delta E-\Delta E' = (\alpha_2-1)\, V_2^2/2g$

As stated earlier, the residual K.E. of flow leaving the basin and expressed as ($\Delta E-\Delta E'$) (as shown in Fig. 1 in this discussion paper), is responsible for scour downstream of the basin. Higher the residual energy, greater will be the scour. Defining Coriolis' coefficient (α) as

$$\alpha = 1/(AV^3) \int u^3 dA \qquad ...(1)$$

where u is the the local velocity through an elementary area dA and V is the mean velocity of flow over the full cross-sectional area A of the channel. In uniform flow, u=V and α =1. It may be seen from Fig.1 (in the discussion paper), that the residual K.E. of flow leaving the basin is given by

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

Since α-value is almost unity at far end downstream where the residual energy is completely dissipated and α_2 is the Coriolis' coefficient at the exit of the basin. The tail water depth ($y_t=d_2$) remains virtually the same after the basin and hence greater the residual K.E. of flow, higher will be the value of α_2. Only way the excess K.E. of flow can be contained by a flow with same depth (y_t) and same mean flow velocity (V_2) is through flow non-uniformity resulting in distortion of flow and scour in the tail channel.

Defining efficiency of a basin (η) as energy dissipator

$\eta = \Delta E'/\Delta E$ ...(3)

$1-\eta = 1-(\Delta E'/\Delta E) = (\Delta E-\Delta E')/\Delta E = [(\alpha_2-1)\,V_2^2/2g]/\Delta E$ ...(4)

Or, $\eta = 1-[(\alpha 2-1)\,V_2^2/2g]/\Delta E$ ...(5)

From Eq.(5) $\alpha_2=1$ when $\eta=1$ and the basin is 100% efficient as energy dissipator. Eq. (2) and (5) shows that basin efficiency reduces as residual K.E. of flow increases. Since the K.E. of normal flow ($V_2^2/2g$) is a negligible quantity compared to tail water depth ($d_2=yt$), even a small amount of residual K.E. of flow will cause a significant rise in α_2-value and the basin efficiency will be less.

Discussor (Mazumder,1994; Mazumder and Naresh,1988) performed several experiments in a basin with diverging side walls having 3:1 side splay (I.e. $e=1-L_b/3$) where L_b is the axial length of the basin. In order to improve the basin performance, discussor performed a large number of experiments with several appurtenances e.g. vanes, baffles, bed deflector etc. Without appurtenances, jump front was skewed and the basin performance was extremely poor as indicated by low values of η and high α_2 - values. With the appurtenances in position, basin performance improved remarkably. η-values were nearly 100% and α_2 - values close to unity (Mazumder,2020). Fig. 2 is a plot of basin efficiency (η) and α_2 for different flows (Q). α_2-values values were computed from velocity distribution measured at the basin end. It may be noticed from Fig.2 that when residual K.E. of flow is only 1% (with η=99%), α_2-values are 3, 4 and 7 corresponding to Q=31,15.5 and 7.75 LPS respectively. With 2% residual K.E. (η=98%), the respective values of α_2 were found to be 4, 6 and 12 indicating highly non-uniform velocity.

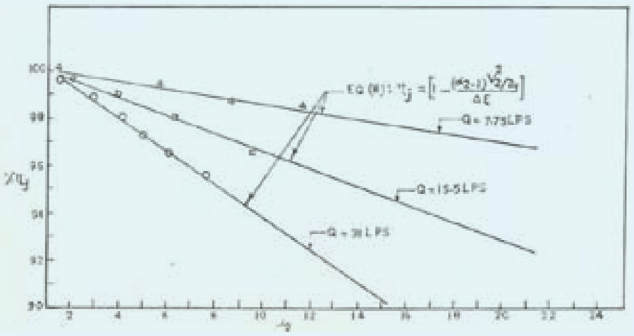

Fig 2 : Showing Jump Efficiency (η_j) against Coriolis' Coefficient (α_2)

Discussor developed another innovative method of improving the basin performance by providing adverse slope (β) to the basin floor. β-value derived by the discussor is given by Eq.(6).

$\beta = \tan^{-1}[(d_1^2+d_2^2+d_1d_2)\tan ¢/(bd_2+Bd_1+2Bd_2+2bd_1)]$ ...(6)

where, b and B are half widths at the entry and exit of basin, d_1 and d_2 are pre-jump and post jump depths respectively and ¢ is the angle of divergence of side walls as shown in Fig.1 and 3. Large number of experiments were performed by the discussor and the experimental values of βopt was found close to the theoretical values given by Eq. 6. With optimum slope of basin floor βopt corresponding to the design Fr1-value, basin performance improved remarkably with η-values almost 100% and the α_2 -value became almost unity indicating very little residual K.E. leaving the basin (Mazumder,2020). Very high scour occurred with level basin floor and scour was nil when the requisite adverse slope was provided to the basin floor as shown in Photographs 1 and 2.

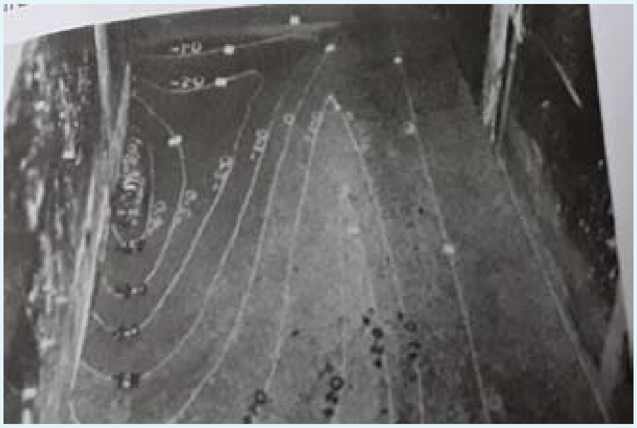

Photo 1 Showing Scour with $\beta = 0^0$

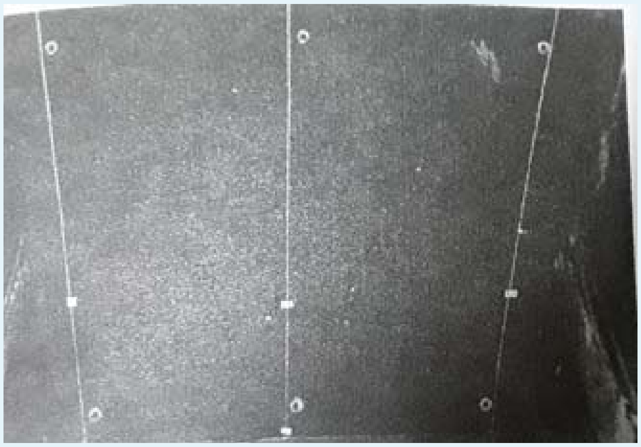

Photo 2 No Scour with $\beta = \beta^{opt}$

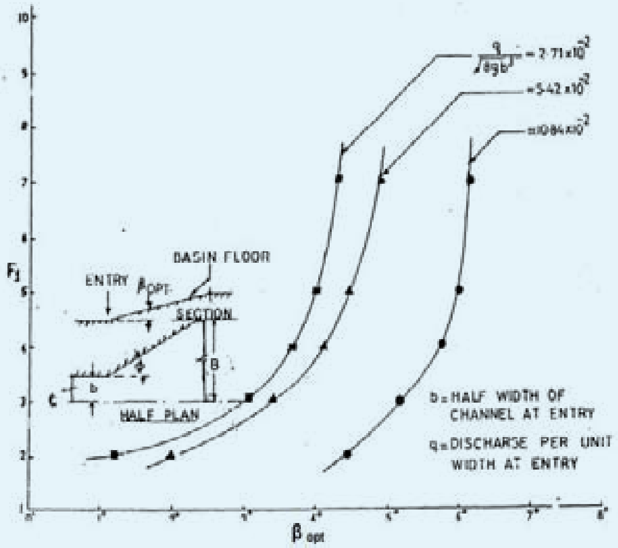

Fig. 3 : Showing Optimum Adverse Slope of Basin Floor (β_{opt}) Against F_1

It will be appropriate here to analyse the reason why high scour occurs when expansion ratio is high. For that, one must understand the mechanism of energy losses in a hydraulic jump. Prejump K.E. of flow (E1 in Fig.1) is converted partly to pressure energy (d_2).The remaining kinetic energy- transfered to production of turbulence- can not be recovered and is called head loss in a jump. Chaturvedi (1963) and Rouse et al, (1951) measured turbulent quantities in a conical diffuser for finding the head losses in terms of turbulent quantities. Production of turbulence is dependent not only upon pre-Jump Fr_1 but also upon the angle of impact of the incoming and outgoing flow (Hinz…). In a skewed jump with inclined jump front, turbulence production is less compared with that in a jump with impact angle 00 to flow axis, found to occur in a classical jump. Authors have given any information neither about the jump front nor about flow conditions downstream with different e-values as per schedule of gate operation.

REFERENCES

Chaturvedi, M.C. (1963) "Flow Characterstics in Axis-Symmetric Expansion, JHE,ASCE, Vol.1999, pp.61-92

Chow,Ven Te (1973) "Open Channel Hydraulics", Pub. By McGraw-Hill International Book Co., International Student Edition, Sigapore

Hager, W.H. (1992)" Energy Dissipaters and Hydraulic Jump" Kluwer Academic Publishers, London 5

Mazumder S.K. and Naresh H.S. (1988) "Use of appurtenances for efficient design of Jump type dissipators having diverging side walls for flumed canal falls " Journal of Civil Engg. Div., The Inst. Of Engrs (I), Vol. 68, pt CI6, May.

Mazumder, S.K. (1994) "Stlling 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), March

Mazumder, S.K.(2001) "Training of River Ganga near Farakka Barrage" National Conf. On Hydraulics and Water Resources – HYDRO 2001 org by ISH & CWPRS, Pune, 6-7 Dec.

Mazumder, S. K. (2011) "Breaching Of Flood Embankments With Particular Reference To Kosi & Farakka Barrages In India" paper published in the journal of Water Energy International by Central Board of Irrigation & Power, New Delhi, March

Mazumder, S.K. (2020) "Flow Transition Design in Hydraulic Structures", Pub. By CRC Press, Taylor & Francis Group, New York, NY 10017, Chapter-4, pp.139-142

Peterka, A.J.(1958) "Hydraulic design of Stilling Basins and Energy Dissippaters" , US Deptt. of Interior, Bereau of Reclamation, Engg. Monograph, 25 : Denever, Colorado, USA

Rouse,H., Bhoota,B.V. and Hsu,E.Y. (1951) "Design of open Channel Expansion", 4th paper in High velocity Flow in Open Channels, A Symposium, Trans., ASCE, PP. 326-346