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LOCAL SCOUR DOWNSTREAM OF A LEVEL APRON WITH AND WITHOUT HYDRAULIC JUMP

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SYNOPSIS

Local scour downstream of a horizontal apron was determined experimentally for two different flow conditions , namely , with and without hydraulic jump , with the same discharge and depth of flow but with different levels of turbulence . Three different lengths of apron were tested , keeping the sediment same size. Non dimensional values of maximum scour depth , its location and volume of scoured material have been plotted against apron length and also against the non dimensional values of bed shear stress , Corrioli's coefficient and turbulence level . Depth and volume of scour was greater for flow with hydraulic jump when the apron length was small . For longest length of apron ,depth of scour was almost same with and without jump but the volume of scour was more with jump. Depth and volume of scour were found to increase with increase in local shear stress , Corrioli's coefficient and turbulence level . The investigation will help in design of protection devices down stream of hydraulic structures.

1.0 INTRODUCTION

Local scour occurs both upstream and downstream of hydraulic structures e.g. weirs and barrages , canal drops, regulators and flow meters etc. Flow upstream of these structures is usually at subcritical stage and it changes to supercritical stage after the control section. The flow is brought back to the subcritical stage after hydraulic jump is formed on the basin floor. Local scour is observed in the structures e.g. syphons, aqueducts, culverts etc. where hydraulic jump does not occur . In these structures, the normal flow section is contracted for economy . Although the flow remains at subcritical stage throughout, there is considerable increase in the velocity of the flow in the contracted (also called flume) reach. Objective of the investigation, reported herein were to determine the local scour on the downstream side of a level apron with and without hydraulic jump formation for simulating the respective flow conditions prevailing in the first and second categories of the structures as discussed above. Local scour is governed by a number of parameters e.g. channel and flow characteristics , sediment characteristics and the geometry of the structure. In the present study , the sediment size and grade was kept the same . Length of the apron was varied and for each of the lengths , scour was observed for two different flow conditions after the apron, namely,(i)subcritical flow preceded by a hydraulic jump and (ii) subcritical flow without any hydraulic jump. The discharge , the flow depth and the Froude number of flow downstream of apron were kept the same , but the flow with jump had high turbulence level compared to the one without jump where the normal turbulence level was very low (3 to 5%). It is felt that the results of the present study will be very helpful in assessment of maximum scour depth , its location and volume of scoured material. Such information will be of use in the design of protection devices e.g. flexible apron, sheet pile cut-offs, foundation depths etc., which are currently designed by empirical formulae e.g. Lacey's equation which does not apply for such hydraulic structures.

2.0 REVIEW OF LITERATURE AND OBJECTIVE OF THE STUDY

2.1 Local scour around bridge piers had been the subject of many investigations throughout the world and numerous formulae have been evolved for scour prediction . Extensive investigations have also been made for local scour downstream of culverts , intakes and pipe outlets. Some of the eminent investigators are Bohan (1970), Cesar Mendoza (1983) and Steven R. Abt (1982, 1984) . There is however very little work available for scour downstream of an apron . Javed Farhoudui and Kenneth Smith (1982) studied scour downstream of an apron with hydraulic jump . The emphasis of the study was to determine the maximum scour depth , similarity of scour holes and time of development of scour. Parameters which were observed to govern the scour were soil type , grain size distribution , velocity of flow , angle and type of jet , depth of tail water , type of appurtenances used and air entrainment etc . Hasan and Narayanan (1985) studied local scour downstream of an apron for jet flow under a submerged sluice gate . They developed a numerical model for predicting the rate of development of scour hole. Theoretical values of scour depth were compared with experimental values . Several equations for estimation of scour depth downstream of different hydraulic structures e.g. plunge pool dissipater , flip bucket dissipater , intakes and stilling basins etc. have been summarized by Breussers and Raudkivi (1991) in the Hydraulic Structures Design Manual published by I.A.H.R . Most of these equations express scour depth as function of discharge intensity (q) , difference in water surface elevations upstream and downstream of the structure (H), sediment size (d_{90}) and tail water depth (Y_3). None of these studies referred above , consider the effect of the residual kinetic energy of flow and the turbulence level of flow leaving the apron . It is not possible to design a dissipater which will ensure total dissipation of energy for all flows and depths of flow downstream. A substantial amount of residual kinetic energy may exist downstream of the basin depending on the flow conditions. Such residual energy causes flow distortion and non-uniformity of velocity distribution in both horizontal and vertical plane resulting in local scour downstream (Mazumdar , 1993). It is well established that the complete decay in turbulence to normal level (3 to 5%) occurs over a length varying from 15 to 22 Y_2 (measured from the jump front) whereas the length of the apron in a stilling basin varies from 3 to 6 Y_2 depending on inflow Froude number F_1 and type of basin. Such flow with high level of turbulence causes local scour below the basin as reported by Hartung and Csallner.

2.2 There is hardly any study of local scour which occurs downstream of structures e.g. Aqueducts. Syphons etc. when the high velocity flow in the flume leaves the structure. A pair of expansive transition connects such structures with the normal flow-section and usually the bed of the channel in the transition reach is either fully or partially paved followed by flexible apron. Scour occurs downstream of expansions, primarily due to change in velocity and roughness. Most of the classical expansions are not free from separation, resulting in flow concentration downstream. Mazumdar (1973, 1994) developed straight expansion of short length by use of triangular vanes and adverse bed slope as a device for control of boundary layer separation and uniform distribution of flow downstream. They are hydraulically more efficient than the conventional designs propounded by Hinds(1928) and Chaturbedi (1963) . Unfortunately many practicing engineer are afraid of using such efficient and economic expansion developed by Mazumdar and continue to use the classical designs invariably causing flow separation and scour downstream. Objective of the present investigation was to study scour profile, maximum scour depth, its location and the volume of scoured material downstream of an apron under two different flow conditions , namely , (i) subcritical flow with high turbulence level as observed at the end of a stilling basin with jump and (ii) subcritical flow with low turbulence level as observed in case of aqueducts without any hydraulic jump.

3.0 EXPERIMENTS:

3.1 All experiments were performed in a tilting steel flume 9m long 1m wide and 0.7m deep . Water was pumped from an underground tank by means of a 15 H.P. centrifugal pump and it was conveyed to the flume by a 15 cm G.I. pipe provided with a calibrated venturimeter. Depth of the flow was controlled by a sluice gate and the flow profile as well as the scour profile were measured by a pointer gauge mounted on a trolley which could move on longitudinal rails. Velocities were measured at a section just before the exit of the apron by using a Prandtl type pitot tube connected with an inclined water manometer. Three different lengths of apron (45,90 and 135 cm) made of cement mortar were tested with and without hydraulic jump. Downstream depth of flow (Y_2) was kept 15 cm and the discharge at 40 lps in all the experiments. For generation of the hydraulic jump, a weir was constructed upstream of the apron, and the crest of the weir was kept at a level so that the jump formed at the weir toe with given tailwater depth of 15 cm. The mean velocity of flow and the Froude number of flow (F_2=0.4) were the same in all the experiments. Turbulence level was, however, different. For those experiments without jump, turbulence level was low (3 to 5%). But in the experiments with jumps, turbulence level was high (12 to 17%), depending upon the apron lengths, namely 0.6 L_j, 1.2L_j, 1.8L_j where L_j is the jump length which was found to be 75 cm corresponding to the prejump Froude number of flow F_1 =2.7 at the toe of the weir. Sand bed was provided downstream of the weir for finding out the scour depth. Mean diameter of sand determined by sieve analysis was 0.41mm. It was so chosen that the normal shear stress after local scour is slightly less than the critical stress (τ_c) corresponding to the given size of sand. This ensured that the local scour occurred only due to local stress concentration and the bed after the local scour is stable. A sand trap was constructed just before the downstream control sluice gate. Figures 1 and 2 illustrate the schematic diagram of the apron with and without the hydraulic jump.

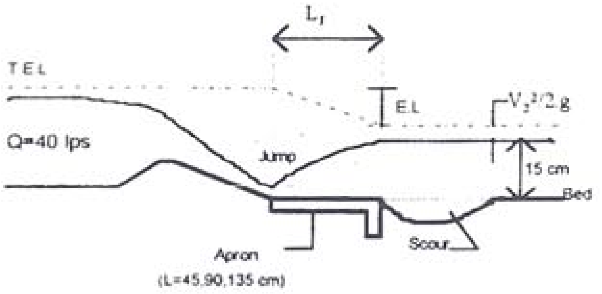


Fig.1. Horizontal Apron (with jump)

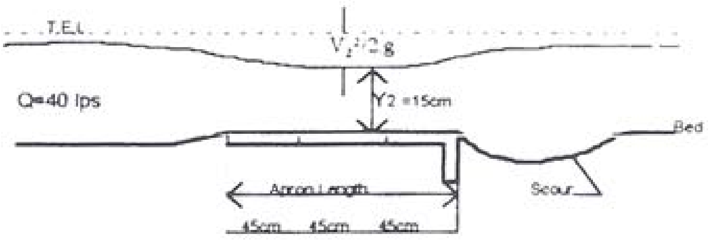


Fig.2. Horizontal Apron (with out jump)

Altogether eight experiments were performed. The summary of results obtained, is shown in Table-1. In each of the experiments the scour was allowed to occur till the maximum scour depth was found to be unaltered. Velocity distribution and scour profiles were measured in each case. Typical distribution of the velocity and the scour profiles for experiment no 1 and 4 are illustrated in Figs. 3(a)and 3(b). Further details are given in Praveen Kumar (1994).

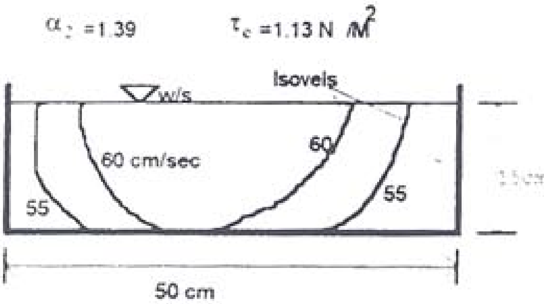


Fig 3(a) Velocity Distribution (without jump)
L=15 cm

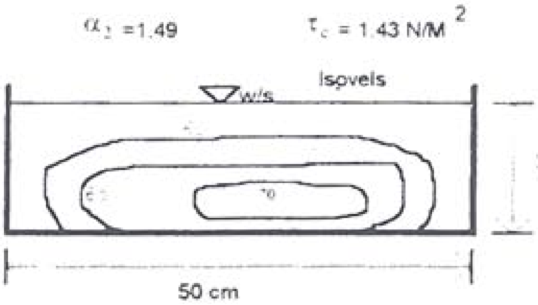


Fig 3(b) Velocity Distribution (with jump)
L=15 cm

4.0 RESULTS

Table-1 gives the results of the different experiments performed with and without hydraulic jump. Kinetic energy correction factor (α_2) and shear stress at the exit end of the apron were computed from the measured velocity distribution and are given in column 5 and 6 respectively. Column 7 gives the ratio of mean to critical stress (corresponding to the given particle size d_{50} = 0.41 mm) which was found to be 0.2215 N/m^2 from Shields curve. Maximum depth of scour (d_{SM}), Volume of scoured material (V_s), location of maximum depth of scour from the end of the apron(L_{SM}) and the total length of the scour (L_{ST}) are given in columns 8.9.10 and 11 respectively and are indicated in figs. 4(a)and 4(b).

TABLE-1 : **SUMMARY OF RESULTS**

Exp No	Apron Length (cm)	Q (lps)	Y_2 (cm)	α_2	τ_0 (N/m^2)	τ_o/τ_c	d_{SM} (cm)	V_s (cm^3)	L_{SM} (cm)	L_{ST} (cm)	Remar-ks
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
1	45	40	15	1.3891	1.13	5.12	10.57	35905	56.0	222.3	With-out Jump
2	90	40	15	1.3317	0.87	3.92	9.32	30688	46.5	252.1	With-out Jump
3	135	40	15	1.2598	0.61	2.74	8.16	23795	37.0	178.2	With-out Jump
4	45	40	15	1.4879	1.43	6.45	13.54	47523	47.0	200.0	With Jump
5	90	40	15	1.3892	1.15	5.10	10.56	36425	39.0	173.1	With Jump
6	135	40	15	1.3482	0.93	4.21	8.24	32750	30.0	197.8	With Jump
7	90	40	20	1.2777	0.60	2.70	9.76	25240	38.0	109.0	Subm Jump
8	90	40	25	1.1905	0.29	1.30	6.34	11180	25.0	92.0	Subm Jump

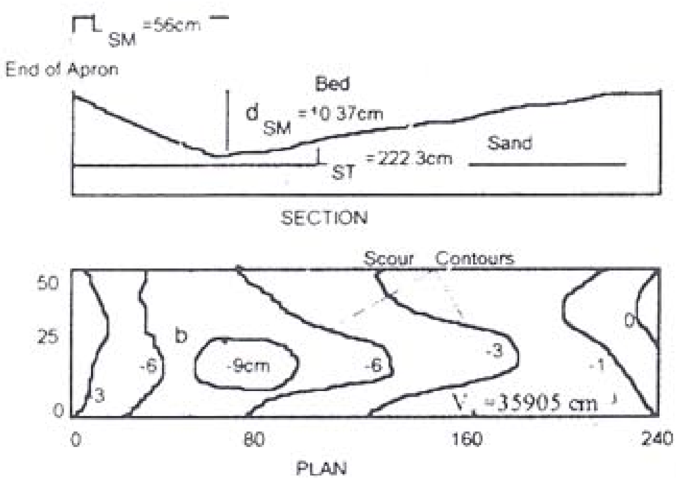


Fig.4(a) Scour Pattern (without jump, L=45 cm)

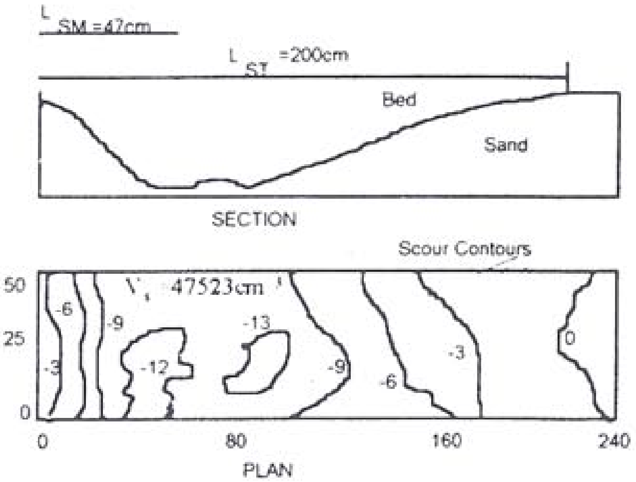


Fig.4(b).Scour Pattern (with jump,L=45cm)

Corrioli's coefficient which gives a measure of residual kinetic energy of flow leaving the apron was computed from each of the velocity contours by using the formula:

$$\alpha_2=\int u^3.dA/A_2.V_2^3 \qquad (1)$$

where dA is the area enclosed between consecutive isovals (u) . A_2 is the area of flow section and V_2 is the mean velocity of flow downstream.

Shear stress(τ_o) and hence the mean shear stresses were computed using Prandtl-Karman equation

$$u/u_*=5.75\log(y.u_*/v)+4.5 \qquad (2)$$

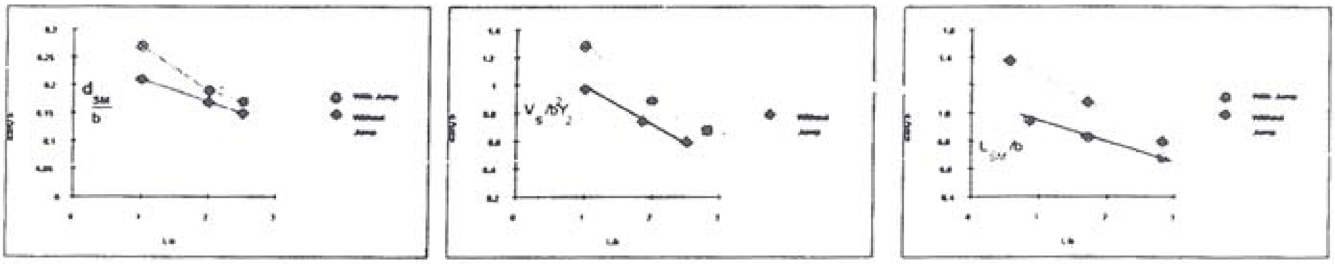
The apron was hydrodynamically smooth . Volume of the scoured material were computed from the scour contour by means of prismoidal formulae.

Turbulence level defined as $\sqrt{u'^2}/V_2$ after hydraulic jump was computed from Kali's(1961) equation

$$K_v=\sqrt{u'^2}/V_2=0.35X/Y_2+2.1+7.6F_1^{-1} \qquad (3)$$

Where F_1 is the prejump Froude number of flow . X is the length of the apron measured from the jump front.

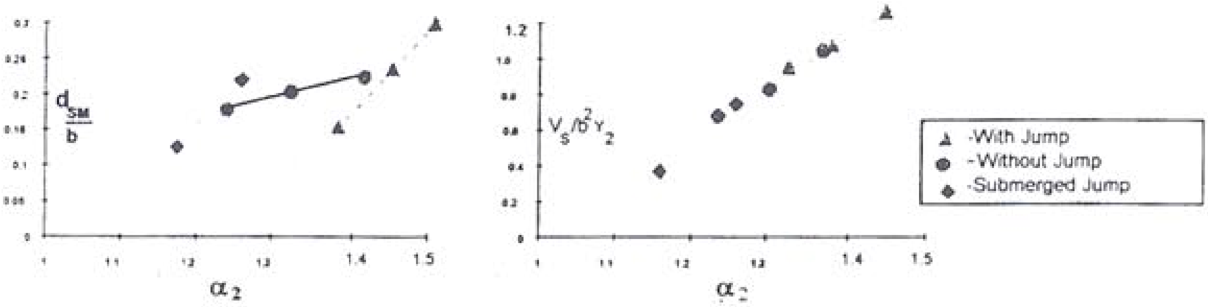
Non dimensional values of maximum scour depth (d_{SM}/b, where b is the width of the apron),volume of the scoured material (V_s/b^2y_2) and the location of maximum scour depth (L_{SM}/b) are shown in Figs 5(a),(b) and (c) respectively. Both the depths of scour and volume of scour are found to increase with jump . However, the difference between the scour depths , for jump and no jump conditions , decreases with increasing length of apron, due to gradual decay in turbulence level. Location of maximum scour depth with jump was found to be nearer the apron than that without jump. for all the floor lengths.



(a) (b) (c)

Fig. 5. Variation of (a)Maximum Depth of Scour,(b)Volume of Scour and (c)Location of Scour with Length of Apron

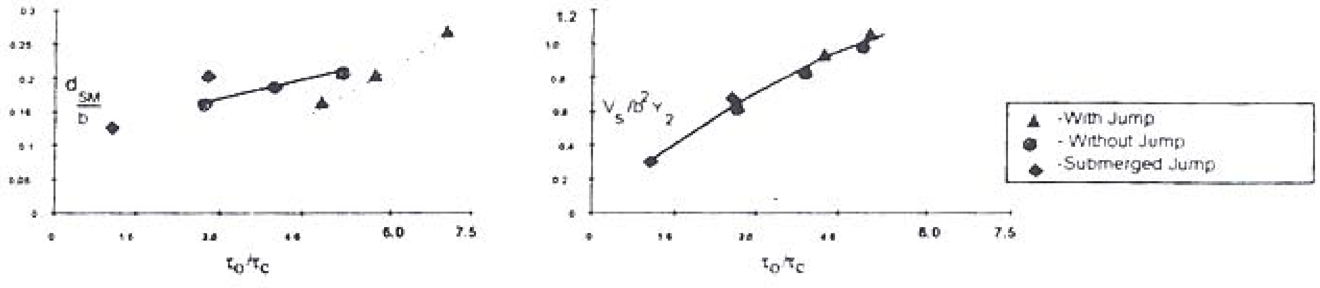
Variation of maximum scour depth and volume of scour are plotted against α_2 in figs 6(a) and 6(b) respectively. It is seen that both the values increase with increase in α_2 i.e. with K.E content of flow leaving



(a) (b)

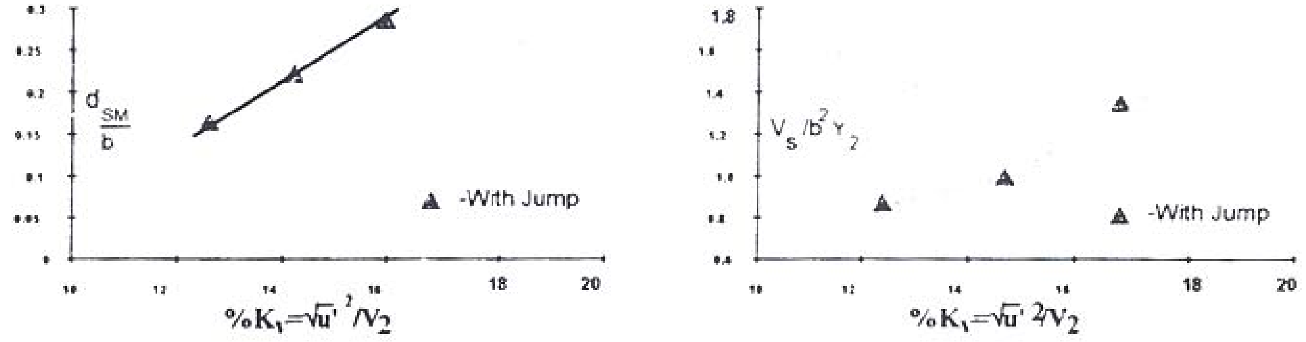
Fig.6.Variation of (a)Maximum Scour Depth and (b)Volume of Scour with Corrioli's Cofficient.

the apron. Similar plots of maximum scour depths and scour volume against τ_o/τ_c are shown in figs. 7(a) and 7(b) which indicate that the both the values increase as the local shear stress increases. Finally, fig 8(a) and (b) illustrate the variation of scour depth and volume (only for hydraulic jump) with variation of turbulence level of flow leaving the basin. Higher the turbulence level higher are the depths and volumes of scour.



(a) (b)

Fig.7. Variation of (a)Maximum Depth of Scour and (b) Volume of Scour with Mean Bed Shear Stress



(a) (b)

Fig.8. Variation of (a)Maximum Depth of Scour and (b) Volume of Scour with Turbulence Level

5.0 CONCLUSIONS

1) Maximum depth of scour (d_{SM}/b) volume of scoured material (V_s/b^2Y_2) and the location of the maximum scour depth (L_{SM}/b) decreases with the increase in length of the apron (L/b) in both cases i.e. with and without hydraulic jump.

2) Maximum depth of scour with and without jump are practically the same for the longest apron (135 cm); but the volume of scoured material (V_s/b^2Y_2) are more with the jump and location of maximum depth of scour (L_{SM}/b) was less with the jump. The difference of L_{SM}/b with and without jump remains more or less the same for all the lengths.

3) Both volume and depth of scour were found to increase with increase in α_2 which is a measure of the K.E of flow leaving the apron.

4) Higher is the bed shear stress τ_o/τ_c more is the depth of volume of scour .

5) Maximum depth and volume of scour were found to increase with rise in turbulence level of the flow leaving the apron with hydraulic jump.

6.0 ACKNOWLEDGMENT

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7.0 REFERENCES

1. Abt. S.R. & Ruff. J.F. (1982). "Estimating Culvert Scour in Cohesive Material "J.of Hyd. Divn. ASCE. vol.108 No Hy1.pp25-34.
2. Abt. S.R., Kloberdanz R.L. and Mendoza. C. (1984) " Unified Culvert Scour Determination" J.of Hyd. Divn. ASCE. vol.110. No 10 .p 1475-79.
3. Bohan J.P.(1970) . "Erosion and Riprap Requirements at Culvert and Storm Drain Outlets". Hydraulics Laboratory Investigation , Report H-70-2. U.S Army Waterways Experiment Station . Vicksburg . Mississippi .
4. Breussers. H.N.C & Raudkivi A.J. (1991) " Scouring" Hydraulic Structures Design Manual . I.A.H.R.
5. Hartung & Csallner . "The Scouring Energy of the Macro -turbulent Flow Downstream of a Hydraulic Jump." J.of Hyd. Research .IAHR.
6. Hassan. N.M.K., Nik and Narayanan R. (1985) "Local Scour Downstream of an Apron" J.of Hyd. Divn. ASCE.vol 111. No 11. Nov. Pp 1371-85.
7. Chaturbedi.R.S (1963). " Expansive Subcritical Flow in Open Channel Transitions" J. Of Institution of Engineers (India). Vol.43. May. pp 447-487.
8. Hinds. J.(1928)" The Hydraulic Design of Flumes and Syphon Transitions" . Trans. ASCE. vol. 92.
9. Kalis. J. (1961) " Diminution de la Turbulence Derriere le Ressuat". Proc. Of IX Congress of IAHR . Dubrovink.pp 43-49.
10. Mazumdar. S.K and Rao J.V (1971) " Use of Short Triangular Vanes for Efficient Design of Wide Angle Open Channel Expansion." J. Of Institution of Engineers (India). vol.51.No.9. Pt c15 . May.
11. Mazumdar S.K. (1993) " River Erosion Downstream of a Barrage "Proc. Of CBI&P (India) Workshop on River Scour . Varanasi (India).. 28-29 April. pp 72-74.
12. Mazumdar. S.K.(1994)" Control of Separation in Open Channel Subcritical Expansion with Adverse Bed Slope " Proc. Of IX Congress of APD-IAHR. 24-26 Aug. . Singapore.
13. Mendoza Cesar . Abt . S.R. and Ruff . J.F.(1983) " Head wall Influence on Scour at Culvert Outlets " J.of Hyd. Divn. , ASCE. vol. 103. no 7. pp 1056-60.
14. Praveen Kumar.(1994) " Study on Local Scour Below a Horizoltal Apron With and Without Hydraulic Jump."M.E.Thesis Submitted to Deptt. Of Civil Engg., Delhi College of Engineering . University of Delhi. May.