CONTROL OF SEPARATION IN OPEN CHANNEL SUB-CRITICAL EXPANSION WITH ADVERSE BED SLOPE

S K MAZUMDER (1), P N DARDE (2)

(1) Professor of Civil Engineering, Delhi College of Engineering, Delhi-110006, India.
(2) Manager, National Hydro-Electric Power Corporation, 98, Hemkunt Tower, Nehru Place, New Delhi-110019, India.

ABSTRACT

With gradual increase in the angle of divergence of the side walls, the different regimes of flow which appear successively in a sub-critical expansion with level bed have been described. The critical angles of divergence corresponding to the different flow regimes have been found experimentally and plotted against the geometry of the expansive passage. Separation of flow and eddies were eliminated by providing adverse slope to the expansion floor. Performance of the expansions with level and sloping beds have been compared to demonstrate the effectiveness of the technique to control separation in sub-critical flow expansion.

INTRODUCTION

Keeping the length of wall(L) constant, if the total angle of divergence (2θ) is gradually increased, the various flow regimes that appear successively in a sub-critical flow expansion are shown in fig.1. At a very small angle, the flow is free from any separation (Fig.1a). Beyond a critical angle ($2\theta_1$), intermittent eddis are observed (fig.1b). A fully developed eddy (fig.1c) appears at a critical angle($2\theta_2$). $2\theta_3$ is the critical angle at which eddies appear on both the sides and a jet flows through the center (fig.1d).

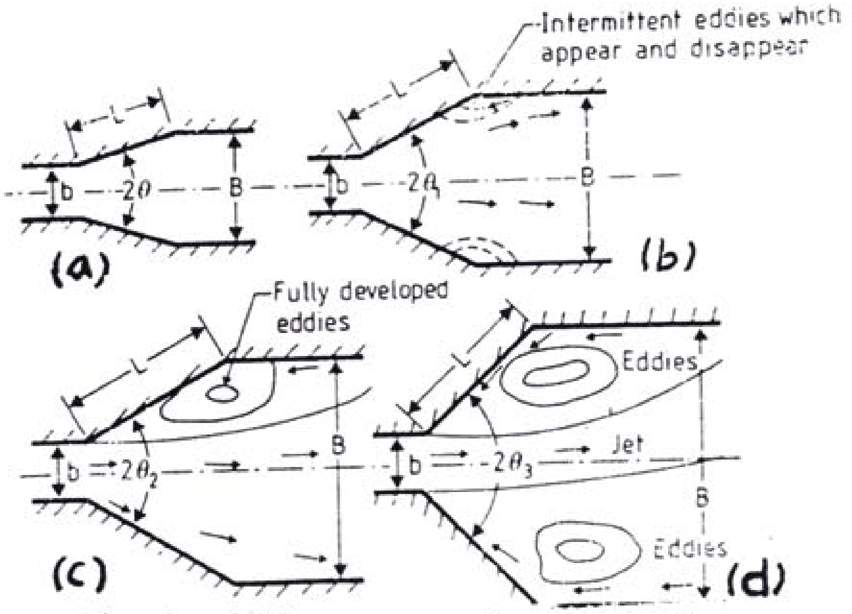
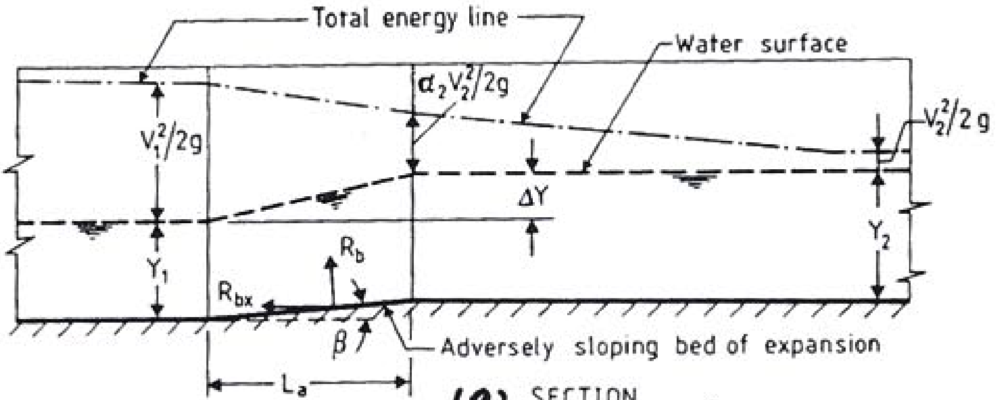


Fig.1 Different regimes of flow

Kline (1959) investigated the nature of eddies in two dimensional diffusers. Smith and Kline (1974) made theoretical studies on transitory eddies in 2-D diffusers. Chaturvedi (1963) found characteristics of flow in axis symmetric diffusers. Different appurtenances eg. rectangular vanes (Cochran and Kline, 1958), baffle piers (Smith and Yu, 1966), triangular vanes (Mazumdar and Rao, 1971) etc. have been used for controlling separation in wide-angle expansions. Each of the devices has its limitations. The present report describes a novel method of separation control by use of adverse slope to the expansion floor.

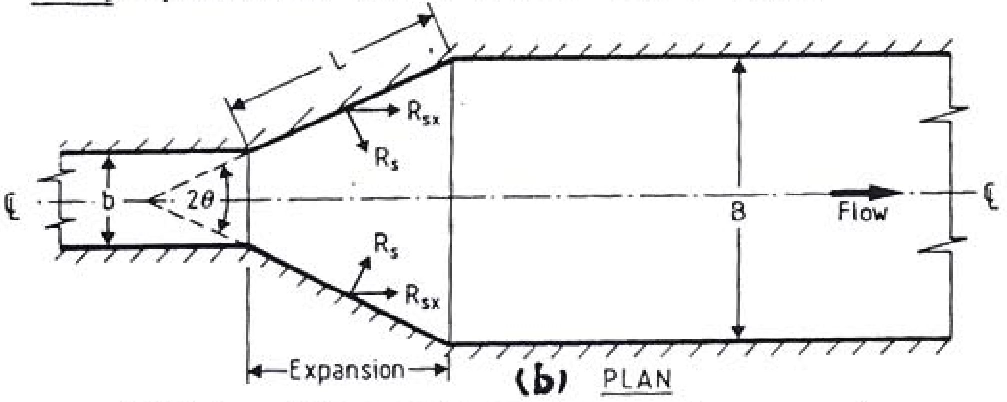
SEPARATION CONTROL BY ADVERSE BOTTOM SLOPE

According to fig.2, the flow through an expansion is subjected to an axial force component Rsx from the side walls(2b). Assuming a linear variation of water surface profile within the expansion and hydrostatic pressure distribution, it may be shown that



(a) SECTION

NOTE: RESIDUAL K·E· OF FLOW = $(\alpha_2 - 1)\cdot V_2^2/2g$



(b) PLAN

Fig.2 Plan and section of expansion

$$2R_{sx} = 1/3\,\rho g\,L_a \tan\theta\,(y_1^2+y_2^2+y_1y_2) \qquad (1)$$

and

$$R_{bx} = 1/3\,\rho g\,L_a \tan\beta\,(by_2+By_1+2By_2+2by_1) \qquad (2)$$

Where ρ is the density of water, g is the acceleration due to gravity, y_1 and y_2 are the depths, b and B are the widths upstream and downstream of the expansion respectively. Equating (1) and (2) and simplifying, the optimum adverse slope (β_{opt})

of the expansion floor may be determined from equation-3.

$$\beta_{opt} = \tan^{-1}[2y_1/b)\tan\theta\ (1+y'+y'^2)/(2+2y'r+y'+r)] \quad (3)$$

Where $y' = y_2/y_1$, $r = B/b$. For a given discharge (Q=10Lps), a given Froude's number of flow at entry ($F_b = 0.6$) and $b = 15$ cm, values of β_{opt} are 5.1°, 6.3°, 8.8° and 9.9° corresponding to 2θ-values of 22°, 29°, 52° and 62° respectively.

PERFORMANCE CRITERIA

Efficiency (η) of an expansion may be defined as

$$\eta = \Delta y/\ \ (v_1^2/2g - v_2^2/2g) \quad (4)$$

Where Δy = recovery of head (fig.2), v_1 & v_2 are the mean velocity of flow before and after the expansions. Another important criteria is the uniformity of velocity distribution just at the exit of the expansion as indicated by Corioli's coefficient

$$\alpha_2 = 1/A_2 v_2^3 .\ \int_{A_2} u^3 dA \quad (5)$$

Where A_2 = area of flow section at the exit, u is the local velocity of flow through an elementary area dA. Higher is the η- value, lower will be the value of α_2, since very little residual kinetic energy will move downstream (fig.2b). In an efficient expansion (with high η and low α_2), there will be hardly any separation at the exit of expansion.

PERFORMANCE OF EXPANSION WITH LEVEL ($\beta = 0^\circ$) AND SLOPING ($\beta = \beta_{opt}$) BEDS

Fig.3 gives the critical angles $2\theta_1$, $2\theta_2$ and $2\theta_3$ corresponding to the different flow regimes obtained with level bed ($\beta = 0°$). Low η- values and high α_2-values (Table-1) indicate extremely poor performance of the level bed expansion at all the angles 2θ=22°, 29°, 52° and 62°. Separation was completely eliminated by use of adverse slope ($\beta = \beta_{opt}$) to the expansion floor as shown in fig.4(a) & (b) and fig.5(a) & 5(b). Comparing the η and α_2-values (Table-1) obtained with level and sloping beds, it is apparent that the performance of an expansion with adverse bed slope (β_{opt}) is far superior

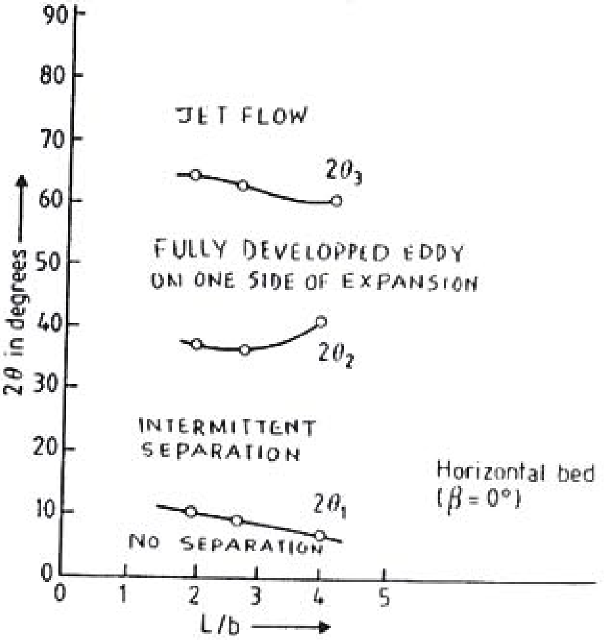


Fig.3 Critical angles for different flow regimes

Table 1 Comparison of Performance of Expansion with and without Bed Slope

Total angle of expansion (2θ)	Performance of Expansion							
	With Level Bed ($\beta = 0°$)				With Adverse Bed Slope (β_{opt})			
	β^0	%η	α_2	Flow condition	β^0_{opt}	%η	α_2	Flow condition
22^0	0	17	1.65	Transitory eddies on one side	5.1	96	1.10	Smooth flow free from any separation & eddy
29^0	0	13	3.00	Enlargement of Eddy on one side	6.3	87	1.14	- do -
52^0	0	11	4.87	Fully developed eddy occupying one side & the live flow moving along other side of expansion	8.8	83	1.18	- do -
62^0	0	10	6.4	Jet flow with eddies on either side & the Jet flow moving centrally	9.9	81	1.17	- do -

to that obtained in case of level bed, for all the angles of expansion.

CONCLUSIONS

(i) various flow regimes in open channel sub-critical flow expansion with level bed are found to be governed by the length (L/b) and total angle of expansion (2θ).

(ii) An effective method of separation control in an expansion is to provide adverse slope (β_{opt}) to the floor, such that the bed reaction (R_{bx}) exactly balances the wall reactions ($2R_{sx}$).

(iii) Hydraulic performance of expansion with optimum adverse bed slope (β_{opt}) given by eq.(3) is excellent when compared with the one having level bed ($\beta = 0°$).

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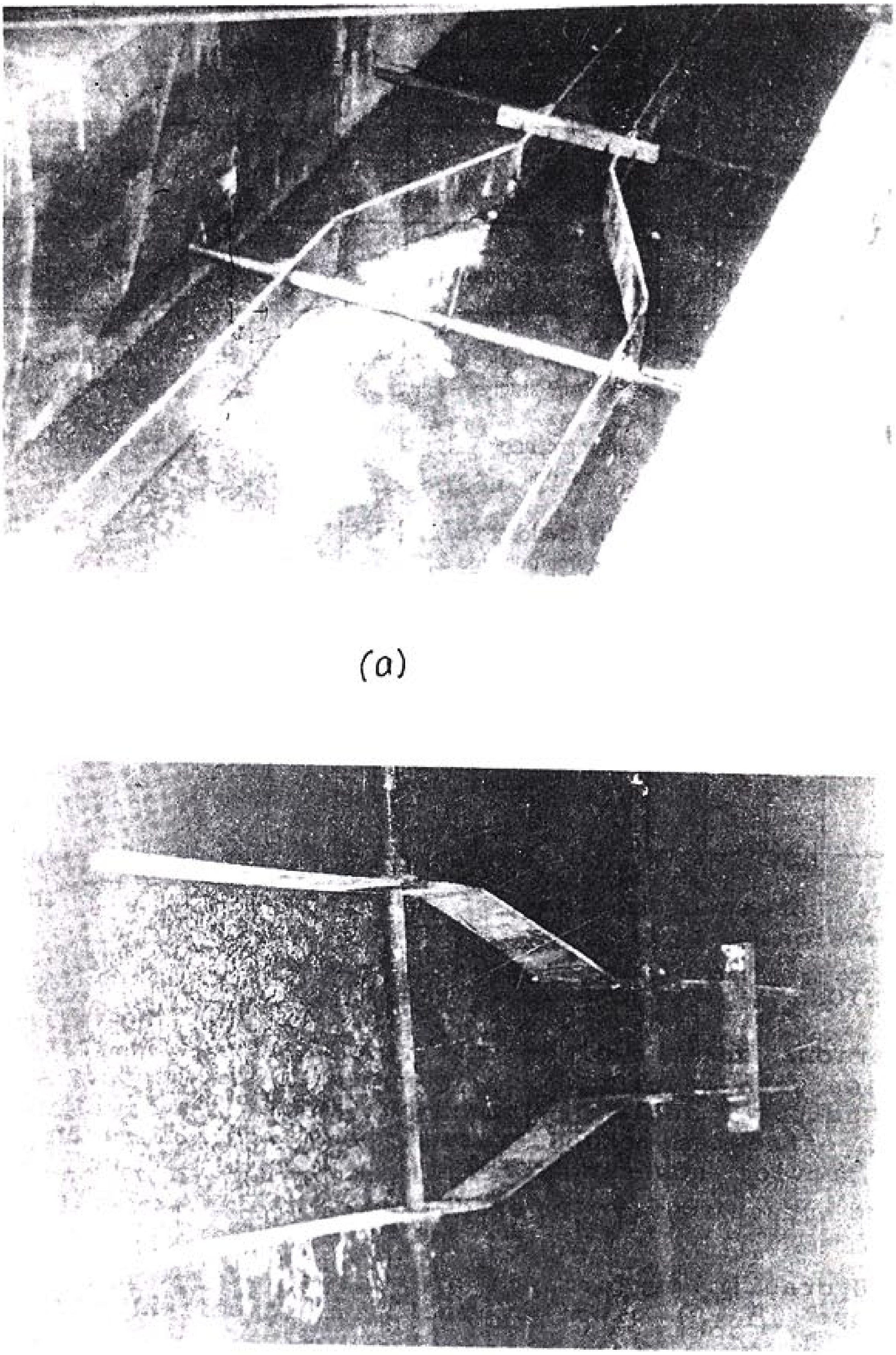
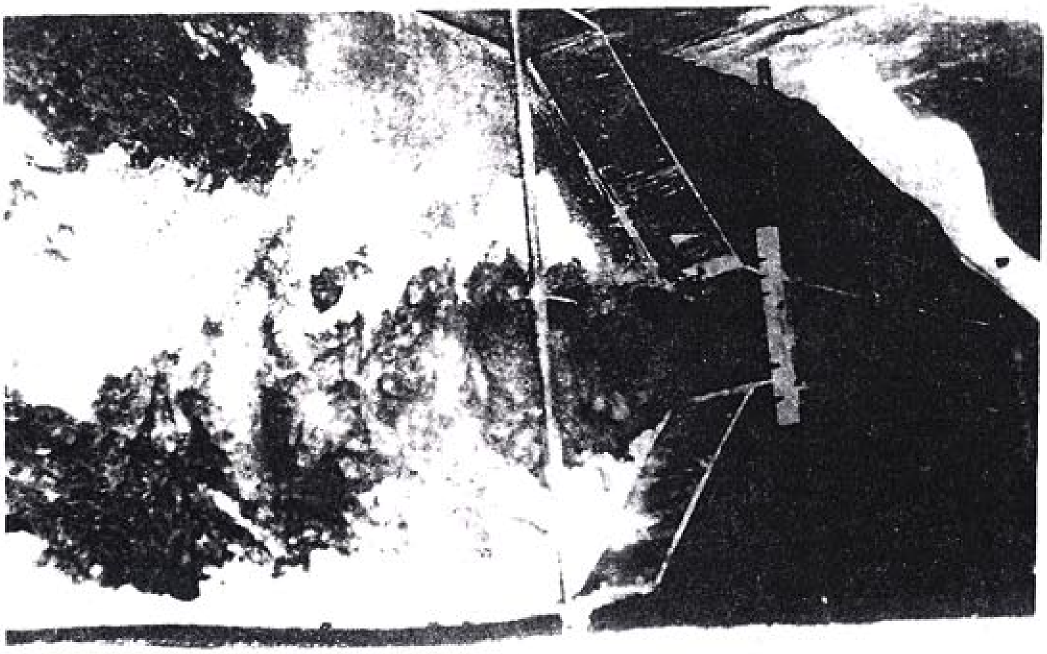


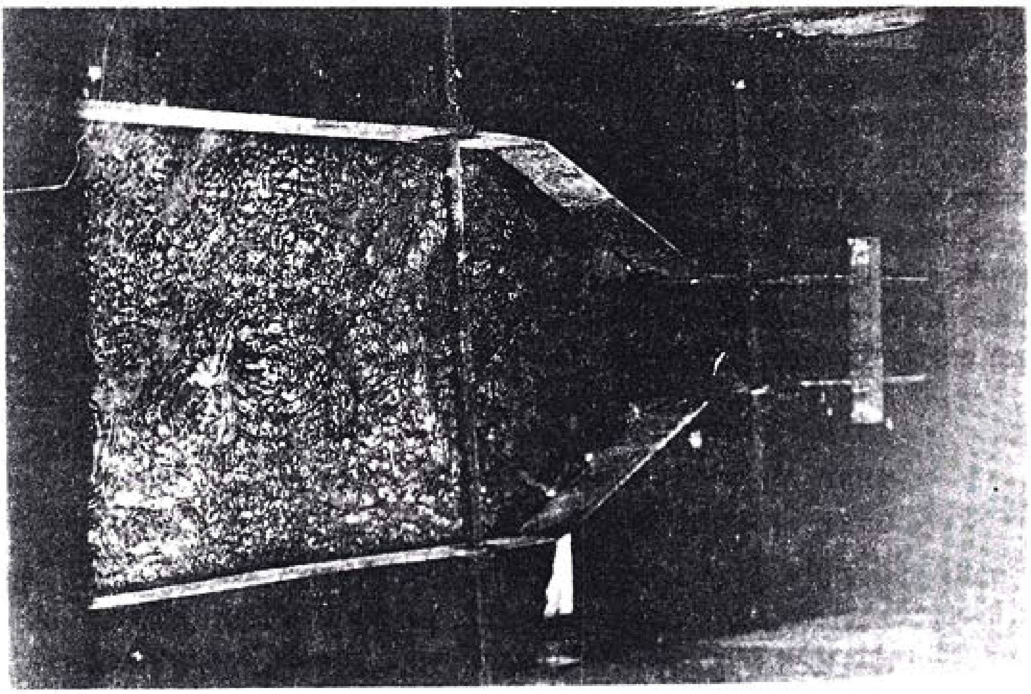
(a)

(b)

Fig.4 Flow Pattern (a) with fully developed eddy on one side at $2\theta = 29°$, $\beta = 0°$, (b) free from any separation at $2\theta = 29°$, $\beta_{opt} = 6.3°$



(a)



(b)

Fig. 5 Flow Pattern showing (a) Jet flow with eddies on either side ($2\theta=62°$, $\beta=0°$), (b) free from separation at ($2\theta=62°$, $\beta=9.9°$)

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LIST OF SYMBOLS

A_2 - Cross-sectional area of flow at exit of expansion
b - Width at the throat
B - Width at exit end of expansion
F_b - Froudes number of flow at entry to the expansion
R_{bx} - Axial component of bed reaction
L - Length of expansion wall
L_a - Axial length of expansion wall
Q - Fow in L/sec
r - B/b
R_{sx} - Axial component of wall reaction
V_2 - Mean velocity of flow at exit
ρg - Unit weight of water
y_1 - Depth of flow at entry to expansion
y_2 - Depth of flow at exit end of expansion
α_2 - Corioli's coefficient at exit end of expansion
β - Slope of bed of expansion with horizontal
β_{opt} - Optimum bed slope of expansion
Δy - Recovery of head = (y_2-y_1)
2θ - Total angle of expansion
η - Efficiency of expansion