SOME CHARACTERISTICS OF FLOW AROUND A 90° OPEN CHANNEL BEND

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Introduction

A knowledge of the flow characteristics in bends is necessary for designing the bend in open channels and is useful for the economical design of canals. Some of the important characteristics like energy loss, velocity distribution, superelevation have been studied in detail by Raju [1], Mockmore [2], Shukry [3] and many others [4, 5, 6 and 7]. But to the knowledge of the authors no literature is available regarding the studies on separation characteristics, except the work of Shukry [3]. Shukry [3, 8] has correlated the position of separation point with Reynolds Number for bends of different central angle (θ) and radius (r_c). Occurrence of hydraulic jump was observed by Mostafa and Tinney [9] and Marris [10]. In the present investigation length of separation, coefficient of contraction, pressure distribution etc. were studied for subcritical flow for various Reynolds Number, Froude Number and Manning's roughness (n).

Experimental arrangements and experiments

The experiments were done in an one foot wide rectangular flume. The test section consisted of a 90° circular bend with r_c/b ratio of 0.5 (b is the width of the flume). Good length of straight portion was provided before and after the bend. Water entered the flume from a head box containing the stabilizing arrangements.

The water surface profile in the flume was measured using standard point gauges. The velocity distribution was measured by means of pitot tube with inclined manometer. The discharge was measured using a V-notch. Length of separation, width of separation, etc., were measured using a scale in combination with dye, pieces of paper or floating material. The direction of flow was found using tufts.

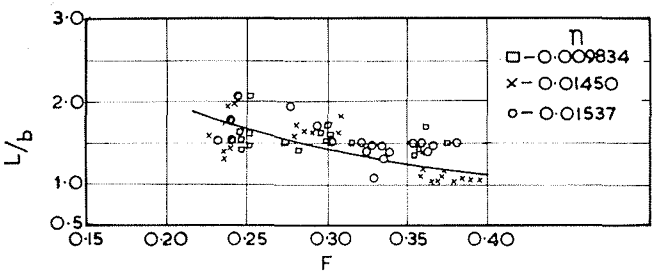
Selected sand was used for varying the roughness, while fixing the sand, care was taken to avoid the formation of lumps or voids and it was distributed uniformly for the bed and sides.

Experiments were conducted with different roughnesses and Froude number and Reynolds number was varied for each experiments.

Results and discussion

Eddy details.

The zone of separation always constitute a part of the source of the loss of energy. The fluctuations in the separation zone quantitatively increased as the Reynolds number increased for a given Froude number. However for the same discharge the fluctuations decreased as the Froude number decreased. Length of separation (L), the



1/ Correlation of parameter L/*b* with Froude number.

maximum width of zone (b'_{max}) and coefficient of contraction (C_c) are discussed in the following paragraphs.

Length of separation is the distance from the point of separation to the point of reattachment. Graves and Renov [11] theoretically predicted by the method of hodograph that for a sharp bend with a sharp corner the maximum width of separation occurs at infinity and the length of separation would also be infinity. But the viscous force of real fluids causes the reattachment and the length of separation reaches a finite value and the maximum width of separation occurs within a short reach. Nondimensional parameter L/*b* was correlated with Froude number. Figure 1 shows that L/*b* decreases as the Froude number increases for all roughnesses used in this investigation. When the Froude number was increased keeping the discharge constant, the length of separation was found to be decreasing and slight increase in maximum width of separation was observed.

When the nondimensional length of separation was correlated with Reynolds number (Fig. 2), L/*b* increased as Reynolds number increased.

Always the maximum width (b'_{max}) of separation zone occurred at about 0.46 to 0.67 times the width of channel from the point of separation. The point of separation appeared at 90° section from the entrance. Figure 3 shows the details of separation zone in plan for various Reynolds numbers for different roughness.

Coefficient of contraction (C_c).

Coefficient of contraction is defined as the ratio of the width of main flow at the maximum width of separation (*a*) to the width of the flume (*b*).

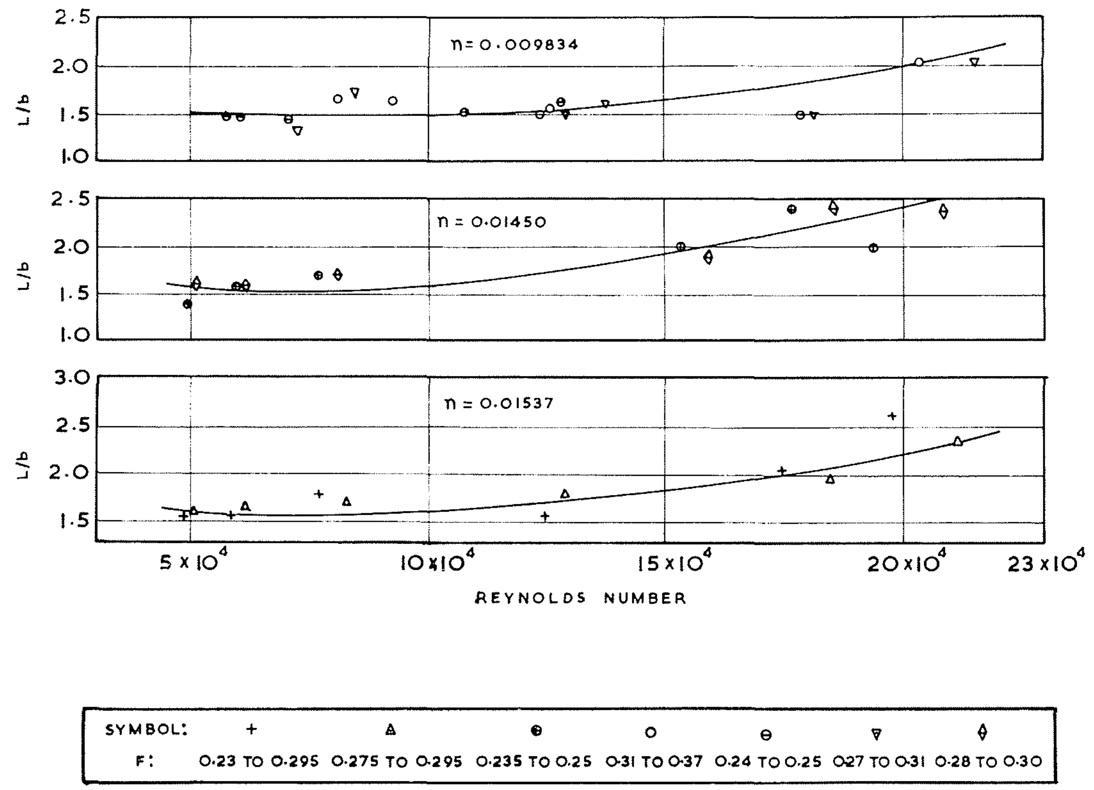
$$C_c = \frac{a}{b} = \frac{b - b'_{max}}{b} = 1 - \frac{b'_{max}}{b}$$

Graves and Renov [11] found that the coefficient of contraction was equal to 0.674 for incompressible flow fluids (experiments conducted in wind tunnel).

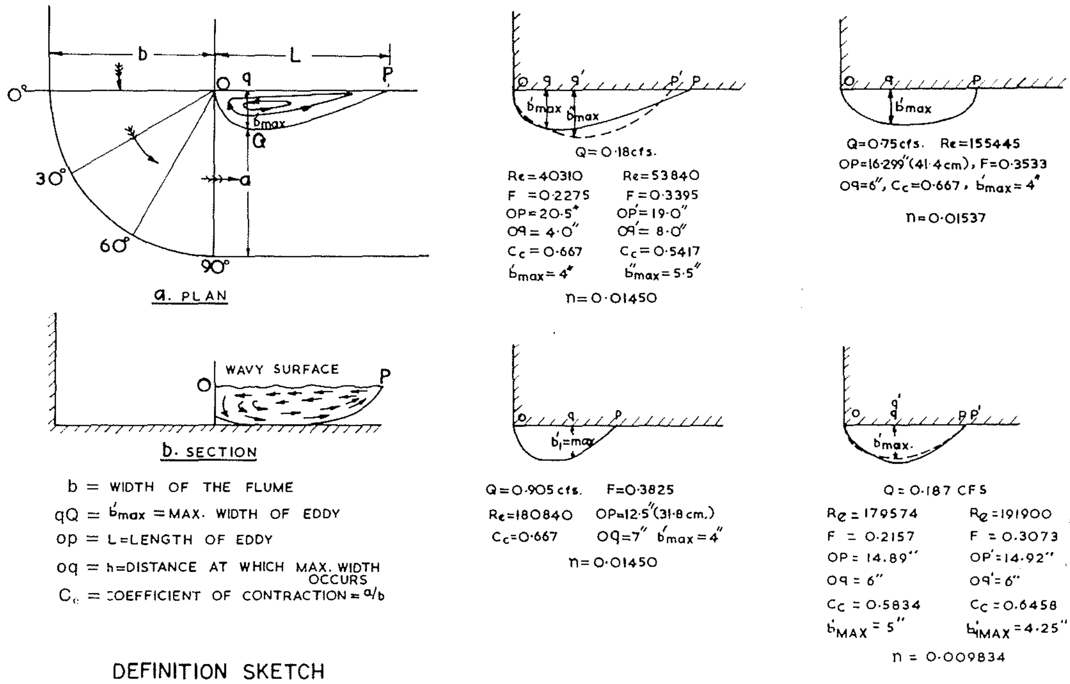
Figures 4 and 5 represent the correlation of coefficient of contraction with Reynolds number and Froude number respectively. Coefficient of contraction is practically constant for the range of parameters considered for all roughness. The mean value is 0.667.

Hydraulic jump and cross wave patern.

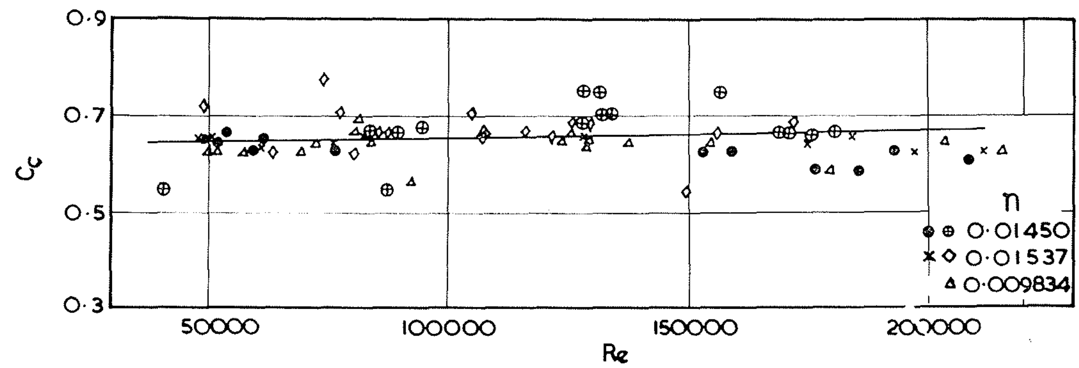
In bends when flow separates in the downstream portion, it reaches supercritical flow when the Froude number covered in the upstream is greater than 0.32. Then the



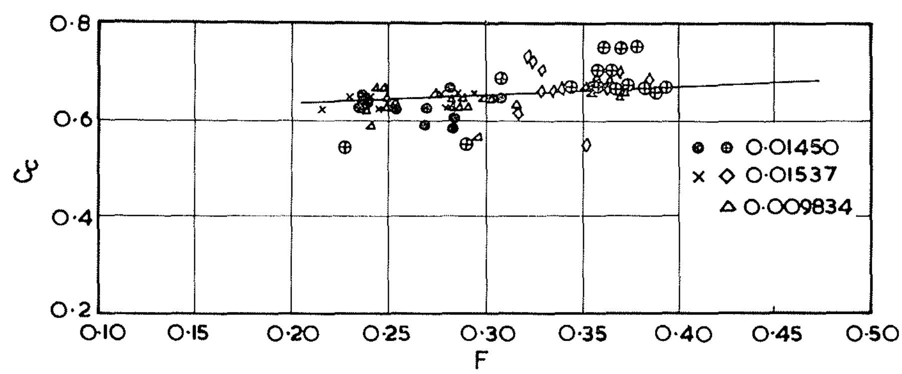
2/ Correlation of parameter L/*b* with Reynolds number.



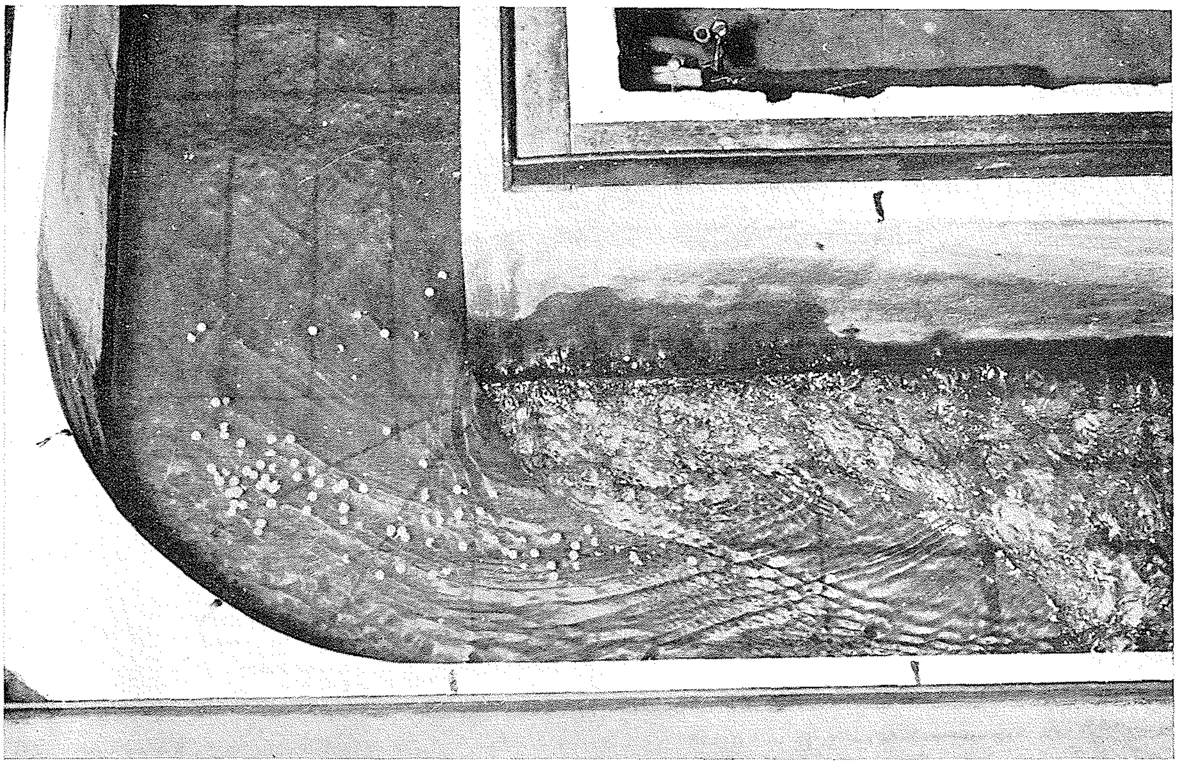
3/ Eddy details for different Reynolds number and *n*.



4/ Variation of coefficient of contraction with Reynolds number.



5/ Variation of coefficient of contraction with Froude number.



6/ Hydraulic jump and crosswave pattern:
Q = 0.18 cfs
Re = 53840
F = 0.3395
n = 0.01450

hydraulic jump occurs in the immediate downstream of the exit of the bend.

The separation zone causes the flow to contract first upto throat (i.e. point of maximum width of eddy) and then to expand within a short distance, causing the flow to change from supercritical to subcritical flow creating a favourable condition for the occurrence of hydraulic jump.

As the surface roughness increases jump will disappear. The presence of jump caused the free surface to be fluctuating and a longer length would be needed for the flow to revert to the uniform flow conditions. The occurrence of hydraulic jump has been cited as an example of vortex breakdown [10, 12]. Thus the flow in a 90° bend with $r_c/b = 0.5$ can also be cited as an example for vortex breakdown.

Even though the flow was subcritical, the fluid particles reflected from the boundary form cross waves. The instantaneous photo (Fig. 6) shows this pattern clearly.

Streamlines.

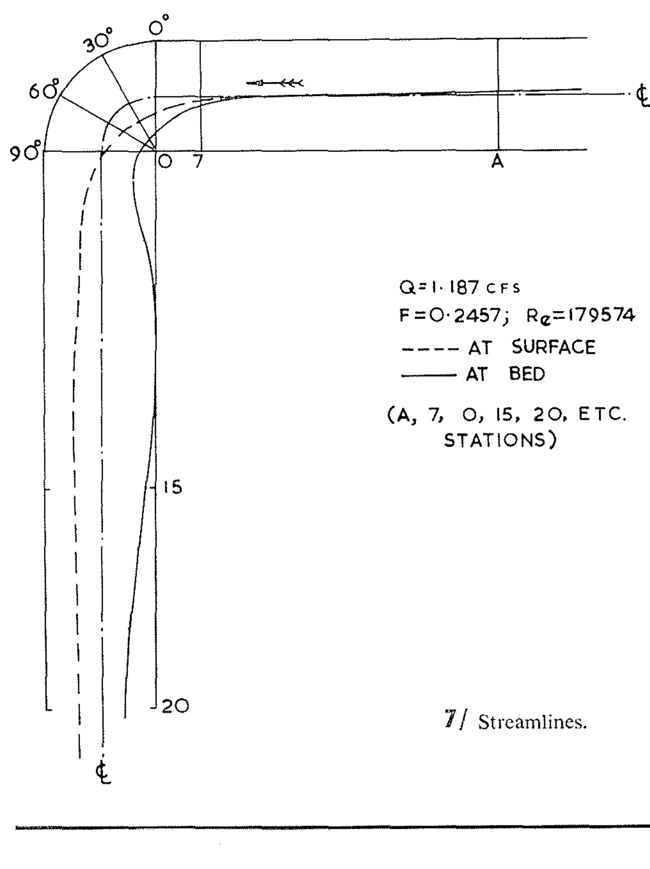
Streamlines were traced along the water surface and bed. The effect of secondary current can be seen in Figure 7. Streamlines are three dimensional in nature. Figure 8 indicates the effect of centrifugal force on the free surface.

Static pressure distribution.

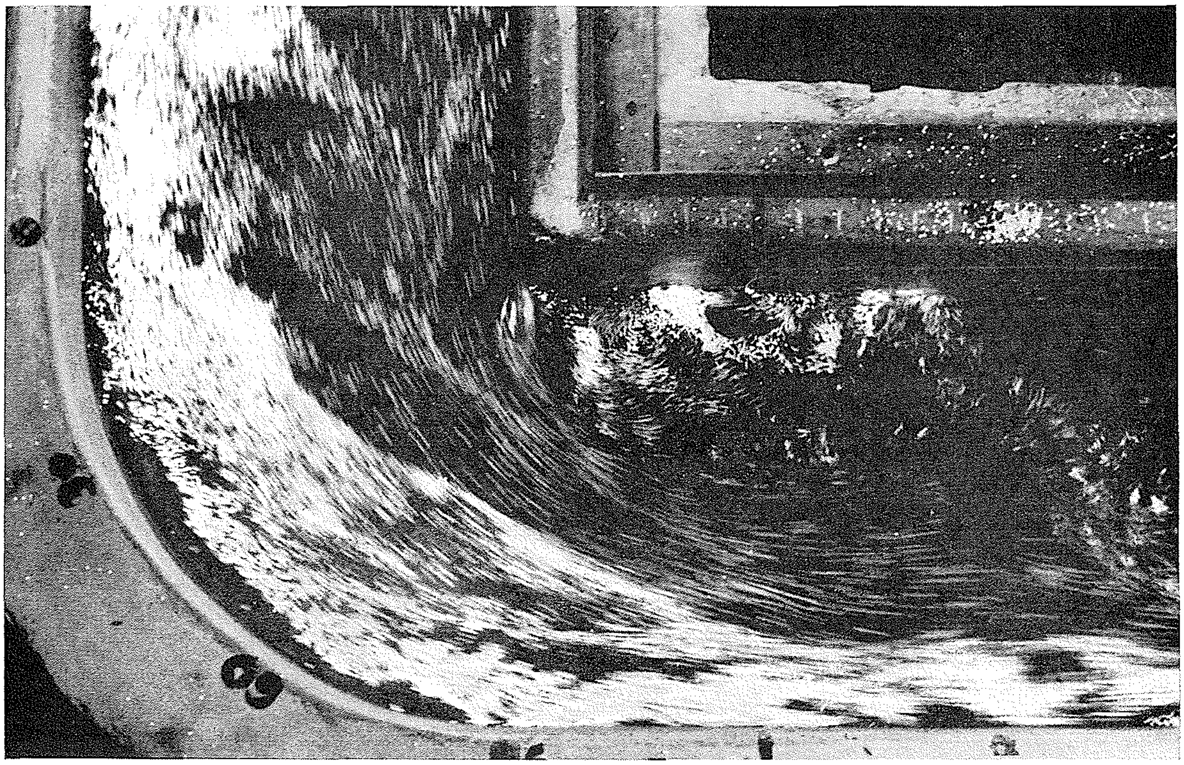
The static pressure in the test section (bend) was measured at different depths and different points, along the radial planes. The static pressure recorded was found to be 3% to 6% less than the hydrostatic pressure distribution near the bed. Thus it can be concluded that the presence of a bend in horizontal plane has the effect of convex bend in a vertical plane regarding pressure distribution.

Conclusions

1. Length of separation increases with the increase in Reynolds number and decreases with the increase in Froude number for all roughness.



7/ Streamlines.



8/ Flow pattern:
Q = 0.1390 cfs
$n = 0.01450$
F = 0.2382
Re = 193200

2. The coefficient of contraction is practically constant for Froude number and Reynolds number for different roughness.

3. Hydraulic jump occurs in the downstream of the bend when the Froude number covered in the upstream of the bend is greater than 0.32.

4. Flow in a 90° bend can be cited as an example of vortex breakdown.

5. Static pressure distribution is 3% to 6% less than hydrostatic pressure distribution, near the bed.

List of symbols

a : width of flow in contracted area;
b : width of flume;
b'_{max} : maximum width of eddy zone;
C_c : coefficient of contraction $= a/b$;
F : Froude number $V/\sqrt{gy}$;
g : acceleration due to gravity;
L : length of separation;
n : Manning's roughness "n";
R_e : Reynolds number $4\,VR/\nu$;
r_c : radius of curvature of bend along the centre line;
V : mean velocity of approach flow;
y : depth of flow;
ν : kinematic viscosity;
θ : central angle of the bend.

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