FOURTH AUSTRALASIAN CONFERENCE
on
HYDRAULICS AND FLUID MECHANICS
at
Monash University, Melbourne, Australia
1971 November 29 to December 3

ENERGY LOSS IN OPEN CHANNEL 90° BEND

by

B.S. THANDAVESWARA* and K. SEETHARAMIAH**

SUMMARY

Energy loss in open channel bend depends on several parameters such as Reynolds number, Froude number, Roughness etc. In this paper the results of the investigation done in a rectangular channel with 90° circular bend of 0.5 r_c/b ratio with, various Reynolds number, Froude number and Manning's n, have been presented. It has been established that Froude similitude is very important while the loss of energy to be estimated in bend and the coefficient of loss of energy will be a minimum when the Reynolds number is in the range of 16×10^4 to 18×10^4.

---

* Senior Research Assistant, Civil and Hydraulic Engg. Dept., Indian Institute of Science, Bangalore 12, India.

** Professor, Civil and Hydraulic Engg. Dept., Indian Institute of Science, Bangalore 12, India.

NOTATION

b = width of the flume

F_A = Froude number $\frac{V_{mA}}{\sqrt{gy_A}}$

g = acceleration due to gravity

h_{fb} = loss of energy due to bend

K_s = sand roughness height

K_1, K_2, K_3 = shape factors

n Manning's roughness

n_k Kutter's roughness

r_c centre line radius of curvature of the bend

R_A hydraulic mean radius at section A.

R_e = Reynolds number $\frac{4\ V_{mA}\ R_A}{\nu}$

S_o = bed slope

V = local velocity

V_{mA} = mean forward velocity at section A

V_{max} = maximum forward velocity at a section

y_A, y = depth of flow at section A, depth of flow

α = energy coefficient

θ = angle of the bend at centre

ν = kinematic viscosity

ζ = coefficient of loss of energy

INTRODUCTION

The laws of resistance for open channel bends are not yet established on rational grounds. In general parameters affecting the coefficient of loss of energy can be expressed mathematically using dimensional analysis as

$$\zeta = f(R_e,\ F_A,\ K_1,\ K_2,\ K_3,\ \frac{\theta}{180},\ \frac{y_A}{b},\ \frac{r_c}{b},\ \frac{K_s}{R},\ S_o) \qquad \ldots (1)$$

where K_1, K_2 are shape factors accounting for the channel cross section and type of bend respectively. K_3 is a factor to account for the sediment effect. The other parameters have been defined under notations. For the present investigation the coefficient of loss of energy is a function of Reynolds number, Froude number and roughness only. This complex phenomenon calls for specifying the limitations of any experimental investigation. Coefficient of loss of energy (ζ) is defined as the ratio of the bend loss (h_{fb}) to the mean velocity head ($V_{mA}^2/2g$) of the upstream reference station A (Fig. 1) where the flow is uniform i.e.

$$\zeta = \frac{h_{fb}}{\left(\frac{V_{mA}^2}{2g}\right)} \qquad \ldots (2)$$

EARLIER INVESTIGATIONS

Boussinesq (1877) [4] was the first to attempt to estimate the loss of energy in open channel bends. His work was of pseudotheoretical in nature. Humphrey and Abbot (1861) [10] , Boer and Urick (1913-14) [10] suggested some emperical formulae for the loss of energy in bends. Scobey[6,7] suggested to increase the value of n_k (Kutter's n) by 0.001 for each 20° curvature, in 100 feet of channel. Several investigators [1,3,5,8,11,12] have conducted investigations, but the results are not satisfactory because of the absence of a standard basis for their correlation.

In the present investigation coefficient of loss of energy has been correlated with Froude number, Reynold's number, y_A/b ratio for different Manning's n.

EXPERIMENTAL SET UP

Fig. 1 shows the details of experimental set up. The flume is of rectangular cross-section with a 90° circular bend with $r_c/b = 0.5$ on a horizontal bed (i.e. $S_o = 0$). Pitot tube was used to measure the velocity distribution. Selected sand was fixed to the sides and bed for getting roughness. First corresponding value of Manning's n was determined. Ratio of y_A/b covered during the investigation was $0.265 \leq y_A/b \leq 1.03$.

RESULTS AND DISCUSSIONS

VELOCITY DISTRIBUTION

Typical non-dimensionalised isovels at different sections are shown in Fig. 2. The velocity measured in 30° and 60° section represents the component in main flow direction and not the true velocity. Pitot sphere was used earlier to measure the velocity components but authors abandoned it as the time required for each measurement was very much. Maximum forward velocity has been found to be near the inside wall. When the forward velocity in the transverse direction was plotted, it was found to follow the free vortex formula except near the walls and at 90° section. In 90° section, the maximum forward velocity occurred always away from the inside wall and towards the outside wall, where the depth was not minimum. This is due to the blocking of flow in the separation zone near the inside wall (Fig. 2, section 90°)

COEFFICIENT OF LOSS OF ENERGY (ζ)

This has been determined by assuming that the energy of flowing fluid is dissipated through solid boundaries. Coefficient of loss of energy has been computed using the specific energy concept and considering the energy coefficient (α) for non uniform velocity distribution into account.

Figs. 3,4,5 show the correlation of coefficient of loss of energy with y_A/b, Reynolds number and Froude number respectively for different Manning's n. Coefficient of loss of energy decreases with the increase in y_A/b ratio reaches a minimum value and then starts increasing for further increase in y_A/b ratio, for a given roughness (n). When results were compared with Shukry's [8] curves, it revealed that for higher Froude number, the coefficient of loss of energy decreases rapidly for a small increase in y_A/b ratio.

Coefficient of loss of energy decreases with the Reynolds number up to certain range and then increases with the Reynolds number. The coefficient of loss of energy was always minimum when the Reynolds number was in the range of 16×10^4 to 18×10^4. But Shukry's results indicated that this value was 18×10^4 for $r_c/b = 0.5$, $\theta/180 = 0.5$ with $y_A/b = 1.00$ and Raju's [5] results showed it to be 11.5×10^4 for 90°, $r_c/b = 1.00$ with $y_A/b = 0.6$. The results of the authors are in agreement with Shukry's results except that the value of ζ is higher. This is due to the different Manning's n and Froude number.

Froude number similarity is very important in open channel. Previous investigators except Hayat [3] did not correlate the coefficient of loss of energy with Froude number. If the Froude numbers are different, the coefficient of loss of energy should also be expected to be different in geometrically similar models. It is interesting to note that the coefficient of loss of energy decreases with the decrease in Froude number for a given Reynolds number and Manning's n. But coefficient of loss of energy increased with increase in Froude number for the same range of Reynolds number and for a given roughness. This coefficient is very high at higher Froude number. This is due to the occurrence of hydraulic jump* in the downstream and due to relatively stronger eddies in separation zone.

By careful comparison of the Figs. 3,4,5 reveal that the coefficient of loss of energy increases as the value of n increases for a given Froude number and Reynolds number.

---

* When the Froude number covered in the upstream (section A) is greater than 0.32, then in the downstream of the bend (where the supercritical flow occurs due to constriction of flow area) the hydraulic jump occurs [Reference 9].

CONCLUSIONS

1. The velocity distribution in bend follows the vortex law in the 90° bend except at 90° section.

2. The coefficient of loss of energy always reaches a minimum value when the Reynolds number is in the range of 16×10^4 to 18×10^4.

3. Froude similitude is very important while the loss of energy to be estimated in bend.

4. Coefficient of loss of energy is a function of Reynolds number, Froude number and Manning's n.

REFERENCES

1. Allen, J. and S.P. Chee, 'Resistances to flow of water round smooth circular bends in open channels', Proc. Inst. of Civil Engrs., London, vol. 23, pp. 423-434, Nov. 1962.
2. Chow Ven Te, 'Open channel hydraulics', International Student Edition, Pub. by McGraw Hill Book Co. Inc., Chapters 1, 5, 16.
3. Hayat, S. 'The variation of loss coefficient with Froude number in an open channel bend', Thesis presented to the University of Iowa at Iowa City in Jan. 1965, in partial fulfilment of the requirements for the degree of Master of Science.
4. Leliavsky Serge, 'An introduction to fluvial hydraulics' published by Constable and Co. Ltd. 10 and 12 Orange Street, London, 1955.
5. Raju, S.P. 'Resistance to flow in curved open channel', (original is in German), English translation by C.E. Bradsley, Proc. ASCE, Vol. 63, pt.2, P. 1834, pp. 49, Nov. 1937.
6. Scobey, F.A., 'The flow of water in irrigation canal', Bul. No.194, pp.18, U.S.D.A. 1915.
7. Scobey, F.C., 'The flow of water in flumes', Tech. Bul. No. 393, U.S.D.A. 1933.
8. Shukry, A. 'Flow around bends in an open flume,' Tr. ASCE, vol. 115, pp. 751-779, 1950.
9. Thandaveswara, B.S., 'Characteristics of flow around a 90° open channel bend,' A thesis submitted for the degree of M.Sc. in the Faculty of Engineering, Indian Institute of Science, Bangalore-12, India, 1969.
10. Woodward, S.M. Howe, J.B., and Posey, C.J. Discussion on 'Mockmore's paper', Tr. ASCE, vol. 109, p. 2217, pp. 626-628, 1944.
11. Yarnell, D.L. and S.M. Woodward, 'Flow of water around 180° bends', Tech. Bul. No. 526, U.S.D.A. Oct. 1936.
12. Yen, C.H. and J.W. Howe, 'Effects of channel shape on losses in canal bend', Civil Engineering, vol. 12, No. 1, pp. 28-29, Jan. 1942.

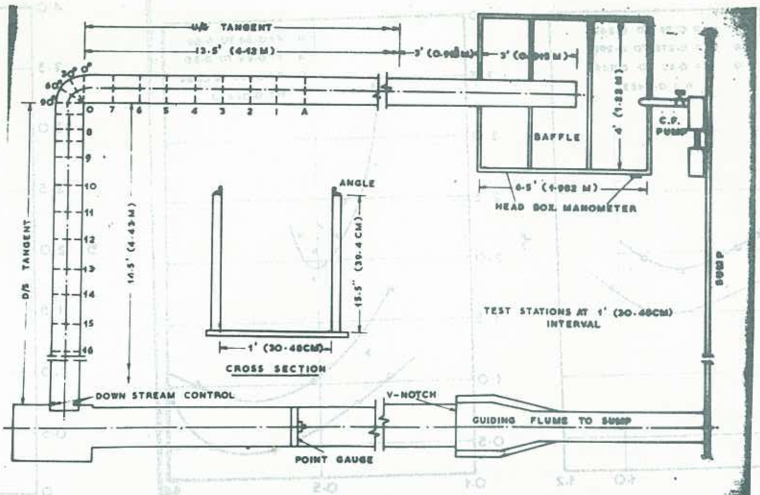
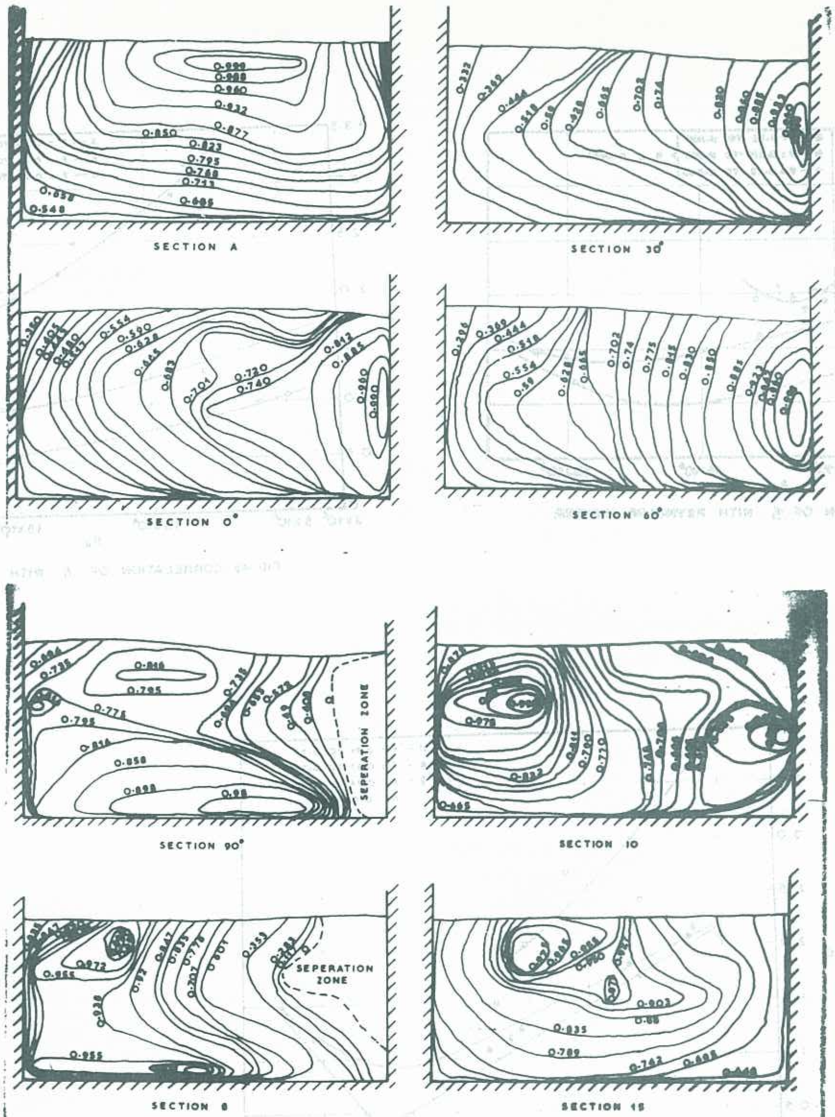


FIG. 1 - PLAN OF EXPERIMENTAL SET-UP



SECTION A SECTION 30°

SECTION 0° SECTION 60°

SECTION 90° SECTION 10

SECTION 8 SECTION 15

Q = 0.2263 CFS (6.42 L/SEC), F_A = 0.2493, R_e = 60976, n = 0.009834

FIG. 2 - NON DIMENSIONALISED ISOVELS (v/V max)

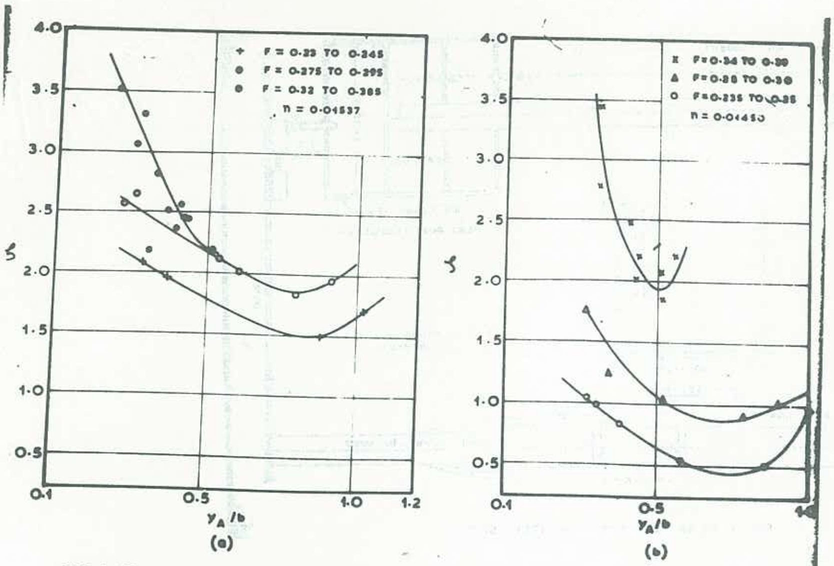


FIG. 3-CORRELATION OF COEFFICIENT OF LOSS OF ENERGY ζ WITH y_A/b

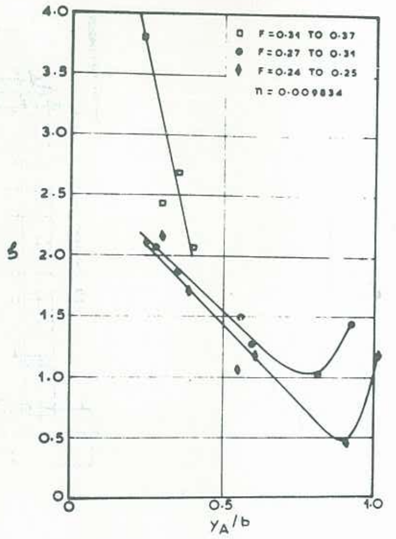


FIG. 3c-CORRELATION OF ζ WITH y_A/b

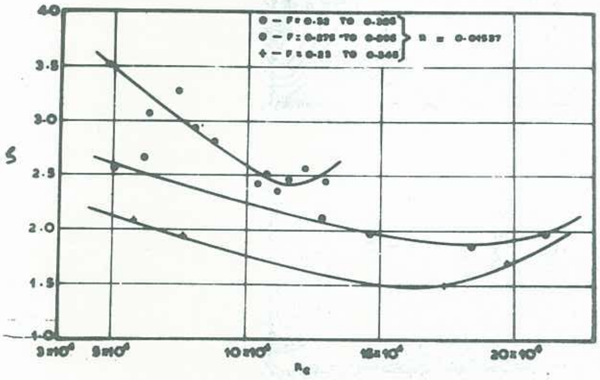


FIG. 4a CORRELATION OF ζ WITH REYNOLDS NUMBER

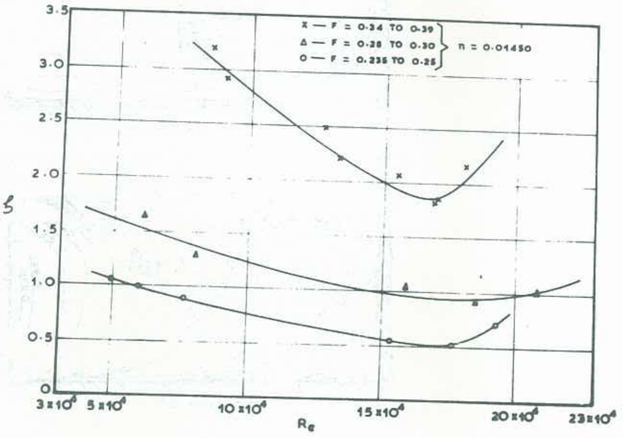


FIG. 4b-CORRELATION OF ζ WITH REYNOLDS NUMBER

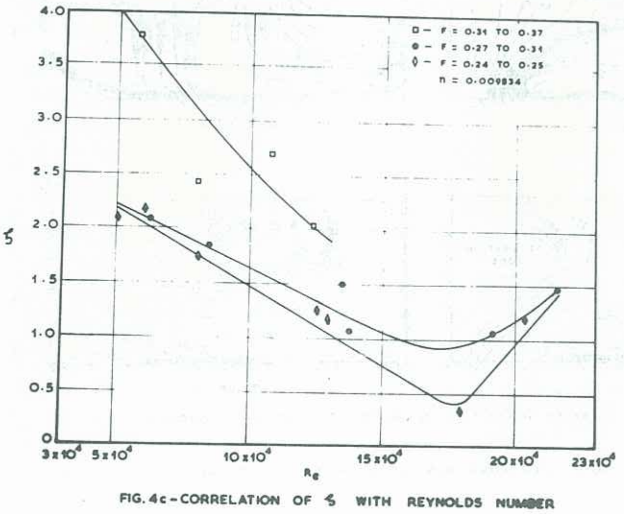
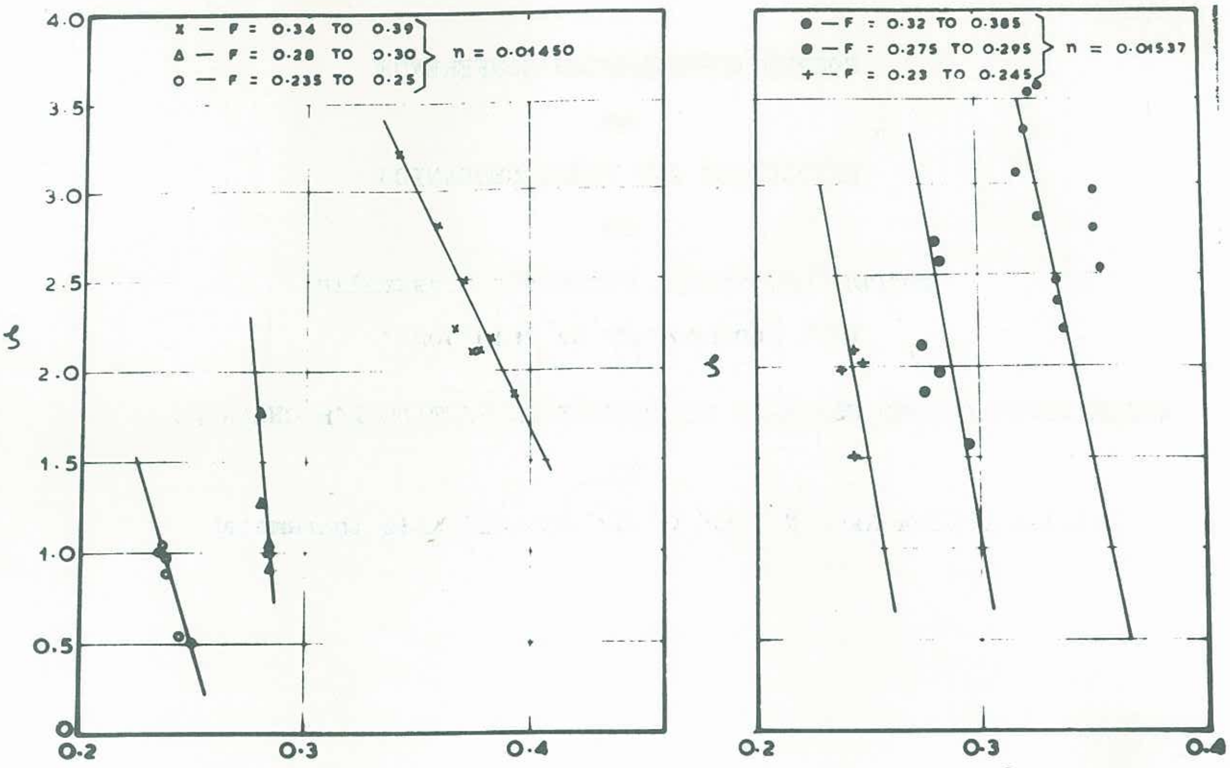


FIG. 4c-CORRELATION OF ζ WITH REYNOLDS NUMBER



(a) (b)

FIG. 5 a-b - CORRELATION OF ζ WITH F

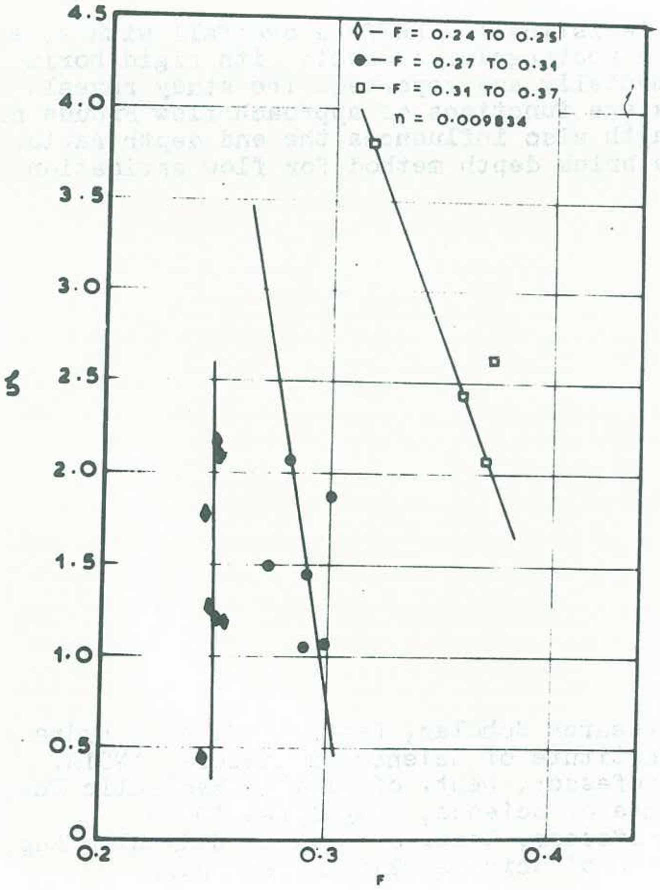


FIG. 5c - CORRELATION OF ζ WITH F