6th Australasian Hydraulics and
Fluid Mechanics Conference
Adelaide, Australia, 5-9 December 1977

An Experimental Investigation of Pressure Recovery Factor in Discharging Manifolds

K. B. SHIVARUDRAPPA
Research Scholar, Hydraulic and Water Resources Engineering Department, College of Engineering, Madras, India
E. V. M. SARGUNAR
Graduate Student, Hydraulic and Water Resources Engineering Department, College of Engineering, Madras, India
and
R. SAKTHIVADIVEL
Professor of Hydraulics, College of Engineering, Madras, India

SUMMARY The effect of various parameters on the pressure recovery factor in discharging manifolds is experimentally investigated using galvanized-iron pipes with orifices as lateral ports. The pressure recovery factor is found to be primarily a function of discharge ratio of the orifice and the pipe, spacing of orifices and pipe Reynolds number. It is insensitive to diameter ratio of the orifice and the pipe and to angle of emergence of jet. The pressure recovery factor varies between 0.64 and 0.95 over the discharge ratio of 0.2 to 1 and is maximum at the discharge ratio equal to 0.5 for the case of single discharging orifice. The interaction of both upstream and downstream orifices on the test orifice is absent beyond a spacing of 16 times the conduit diameter from the test orifice.

1 INTRODUCTION

A manifold may be defined as a flow equipment in which fluid enters or leaves through porous side walls due to the action of a differential pressure. Manifolds commonly used in flow distribution systems can be broadly classified into four types, namely, dividing (discharging) or combining flow manifolds and parallel or reverse flow manifolds. The parallel and reverse flow systems are combinations of the basic dividing and combining flow manifolds interconnected by lateral branches. The dividing type manifolds are widely used in navigation lock systems, in sprinkler and sub-irrigation systems in agriculture, in outfall diffusers for the offshore disposal of sewage in pollution abatement, in exhaust systems in fume removal applications and in heating and cooling ducts in environmental control. There are two major aspects of design and flow analysis of dividing manifolds. One is to predict the performance of a manifold for a given condition and the other is to provide the uniform outflow distribution along a manifold. Various flow parameters such as friction factor, pressure recovery factor, velocity distribution correction coefficients and orifice discharge coefficient are involved in the analysis of dividing manifolds. The characteristics of these parameters and particularly that of pressure recovery factor have not been thoroughly investigated so far. The pressure recovery in discharging manifolds which has been variously termed the "diffusion", "inertia" and "static regain" effect, is designated as the pressure recovery factor in this paper. It has been reported that for the piping systems where the distance between adjacent branch points is fairly long, the pressure recovery factor obtained by a single branch fitting can be applied for flow analysis because the state of flow of branch fitting is little affected by the adjacent one (McNown 1954, Soucek and Zelnick 1945). On the other hand, when the branch fittings are very closely spaced there will be interaction due to the presence of these branch fittings in the state of flow. As to date (1977) there are only few studies on the pressure recovery factor of dividing manifolds with closely spaced lateral ports or orifices (Shivarudrappa, et al 1976, Kubo and Ueda 1969). This parameter will have a strong influence on the design of discharging manifolds, especially, when the branch points are very closely spaced.

2 ANALYSIS OF FLOW

Considering a control volume, as shown in Figure 2, for an incompressible, isothermal fluid and applying momentum balance, ignoring friction, one can get

$$\frac{p_2 - p_1}{\varrho} = V_1^2 - V_2^2 - R_d\, V_1\, V_3\, \frac{A^3}{A_1} \qquad (1)$$

in which p_1 and p_2 are the pressures upstream and downstream of orifice in the main conduit respectively, V_1 and V_2 are the mean velocities upstream and downstream of orifice in the main conduit, $V_y = V_3$ and $V_x = V_1$ are the normal and longitudinal components of orifice discharge velocity, A_1 and A_3 are the conduit area upstream of port and port area, ϱ is the density of fluid and R_d is the pressure recovery factor to allow for an uncertainty in the axial momentum transported across port area A_3.

By applying continuity equation, one can rewrite (1) in non-dimensional form as

$$\frac{p_2 - p_1}{\varrho V_1^2/2} = 2\,\frac{Q_3}{Q_1}\left(2 - R_d - \frac{Q_3}{Q_1}\right) \qquad (2)$$

or as

$$R_d = 2 - Q^* - \frac{\Delta h\, g}{Q^*\, V_1^2} \qquad (3)$$

in which Δh is the piezometric head difference $(p_2/\gamma - p_1/\gamma)$ obtained by extrapolating the hydraulic gradient lines upstream and downstream of port to branch point, Q_1 and Q_3 are the conduit discharge upstream of port and port discharge respectively, $Q^* = Q_3/Q_1$, γ is the specific weight of fluid and g is the acceleration due to gravity.

From a dimensional analysis, one can write R_d in a functional relationship as

$$R_d = F\left(\frac{D_3}{D_1}, \frac{Q_3}{Q_1}, R_e, \frac{S}{D_1}, \Theta\right) \quad (4)$$

in which D_3 is the orifice diameter, D_1 is the conduit diameter upstream of orifice, D_3/D_1 is the diameter ratio, Q_3/Q_1 is the discharge ratio, $R_e = VD/\nu$ is the pipe Reynolds number, ν is the kinematic viscosity of the fluid, $\frac{S}{D_1}$ is the relative spacing of orifices and Θ is the angle of jet issuing from the orifice with reference to the vertical.

The objective of the present experimental study is to investigate the influence of various parameters, as given in (4), on the pressure recovery factor, R_d.

3 EXPERIMENTAL SETUP AND PROCEDURE

3.1 Experimental Equipment

A schematic sketch of the experimental setup is shown in Figure 1. The main conduit was a 20mm internal diameter galvanized iron pipe of 10m length connected to a constant level supply tank kept at a head of 4.2m above the conduit. Water was pumped to the supply tank by means of 1.5kW pump. The central 3m portion of the conduit was used as test section. The simple orifices were drilled at the bottom of the conduit at the required points. All burrs were carefully removed after drilling. Piezometric tappings were taken diametrically opposite to the line of orifices at 100mm spacing along the test section of the conduit and connected to central pressure manifold piezometric panel. The applied pressure in the piezometric panel was measured by means of an open column U-tube mercury manometer.

3.2 Experimental Details

The details of experimental tests conducted are given below.

3.2.1 Tests on single central orifice

Series of tests were conducted to study the effect of D_3/D_1 on R_d by drilling simple, sharp edged circular orifices at the mid point of the test section. Separate tests were conducted for different orifice diameters of 4mm, 6mm, 8mm, 9mm, 10mm, 11mm, 12mm and 14mm, taking one at a time.

3.2.2 Tests on central orifice with one upstream orifice only

Seven orifices of 4mm diameter were drilled in line and upstream of the test orifice of 4mm diameter at distance of $3D_1$, $4D_1$, $6D_1$, $8D_1$, $10D_1$, $12D_1$ and $16D_1$ to study the interference of upstream orifice (particularly the spacing) on R_d of the test orifice. Series of tests were conducted with one upstream orifice discharging at a time, in addition to the test orifice, keeping the remaining orifices closed. The tests were repeated as above with the orifice diameter changed to 8mm.

3.2.3 Tests on central orifice with one downstream orifice only

Seven more orifices of 4mm diameter, in addition to the seven orifices (4mm) on the upstream side, were drilled in line and downstream of test orifice at distance of $3D_1$, $4D_1$, $8D_1$, $10D_1$, $12D_1$ and $16D_1$ to study the influence of the spacing of the downstream orifice on R_d of the test orifice. Series of tests were conducted with one downstream orifice discharging at a time, in addition to the test orifice, keeping all the remaining orifices closed. The tests were repeated as above with orifice diameter changed to 8mm.

3.2.4 Tests on central orifice with one orifice on either side

All the fifteen orifices of both 4mm and 8mm diameter, including the test orifice, used for the tests 3.2.2 and 3.2.3 above were made use of in this test also. Again, series of tests were conducted, by keeping one pair of equidistant orifices open at a time, to study the combined effect of upstream and downstream orifices on R_d of the test orifice.

3.3 Experimental Procedure

The flow ratio through the orifices and at the end section of the main conduit were measured volumetrically. The overall flow rate at the entrance to the main pipe was found by taking the sum of flow rates through the orifices and the flow rate at the end section of the main conduit. For each test run the experiment was repeated twice and average of the two sets of readings was taken as representative data. Care was taken to remove air bubbles, if any, in the piezometric hoses at the beginning of each run. Temperature of water was recorded at every thirty minutes and the variation of temperature was found to have negligible effect on the viscosity of water. The specific gravity of mercury used in the U-tube manometer was carefully determined before starting the experiment.

The measured piezometric heads were plotted on either side of the test orifice and hydraulic gradient lines passing through most of the points were drawn and extrapolated to meet the vertical line drawn at test orifice. The vertical intercept was taken as Δh, the pressure head recovered. As all the quantities are known on the right hand side of (3), the R_d value can be computed.

4 DISCUSSION

Figure 4 shows the influence of Q_3/Q_1,

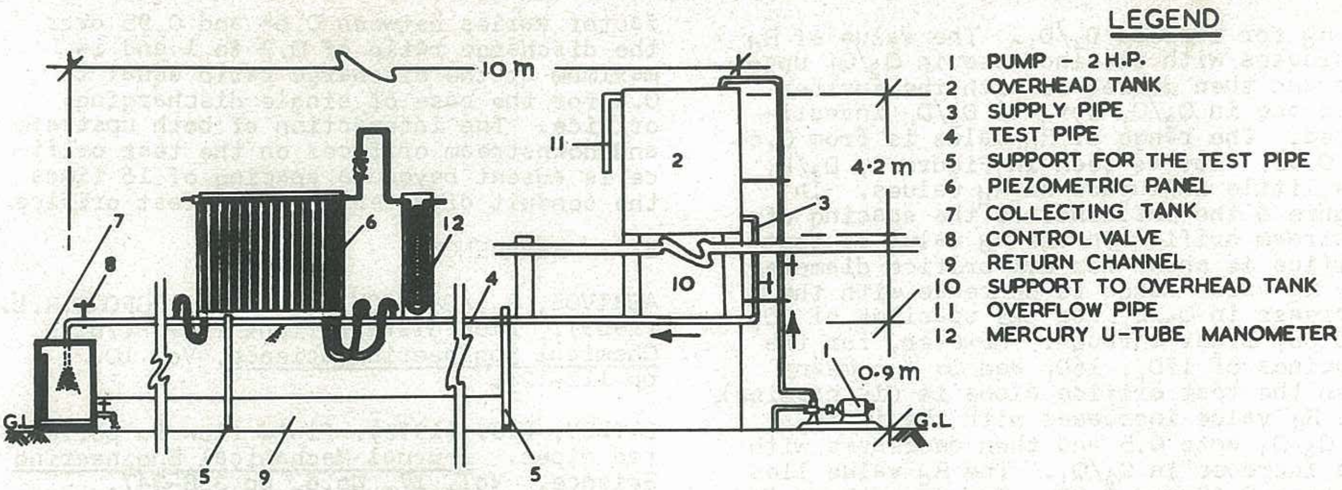

Figure 1

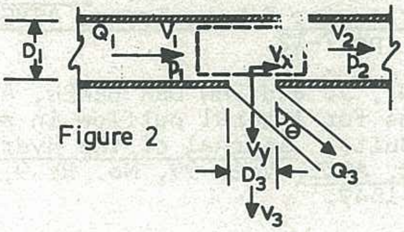

Figure 2

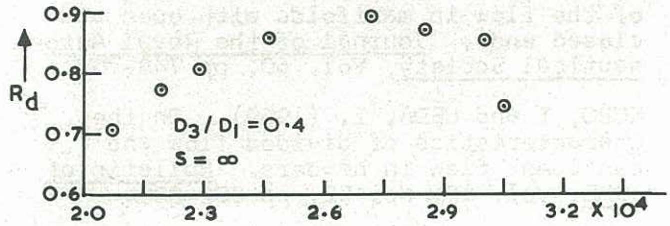

Figure 3

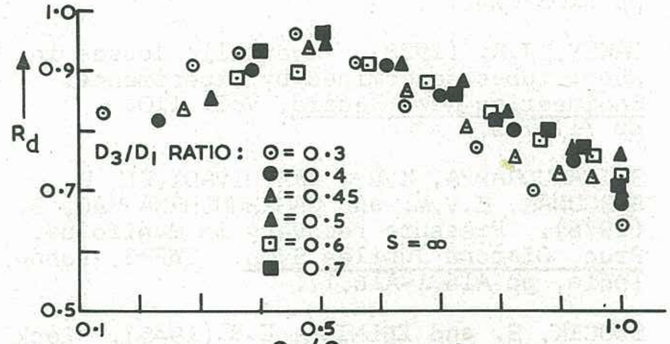

Figure 4

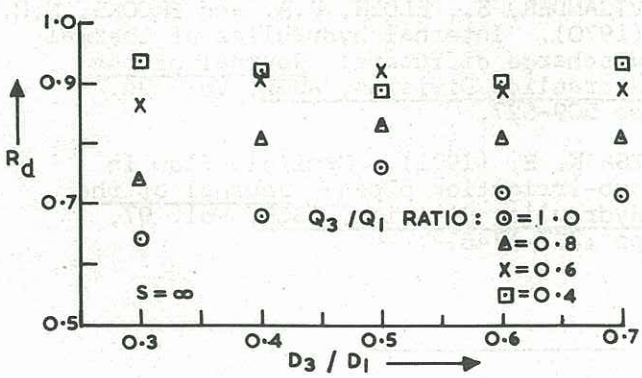

Figure 5

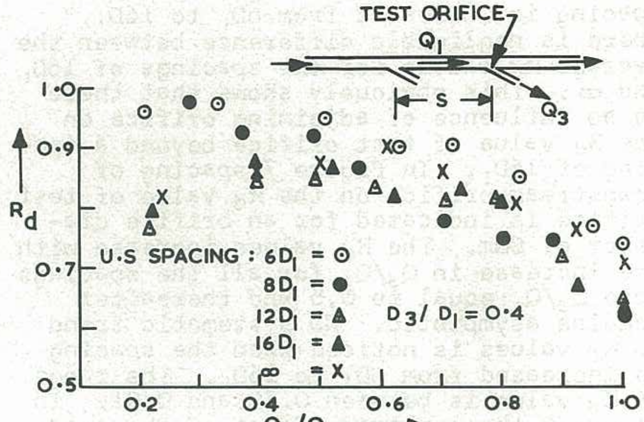

Figure 6

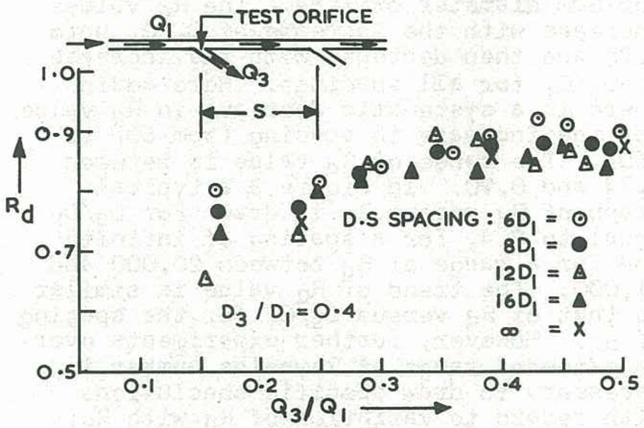

Figure 7

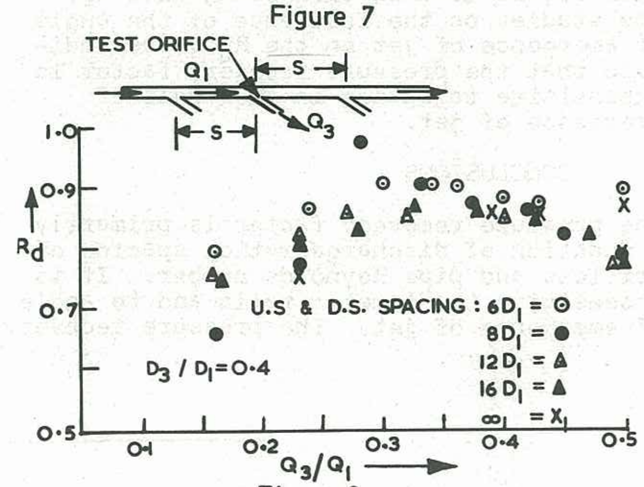

Figure 8

on R_d for various D_3/D_1. The value of R_d increases with the increase in Q_3/Q_1 upto 0.5 and then decreases with the further increase in Q_3/Q_1 for all D_3/D_1 investigated. The range of R_d value is from 0.64 to 0.95. But as seen in Figure 5, D_3/D_1 has little influence on R_d values. In Figure 6 the influence of the spacing of upstream orifice on the R_d value of test orifice is shown for 8mm orifice diameter. The R_d value tends to decrease with the increase in Q_3/Q_1 for the spacings of $6D_1$ and $8D_1$ right through. However, for the spacings of $12D_1$, $16D_1$ and ∞ (∞ means when the test orifice alone is discharging), the R_d value increases with the increase in Q_3/Q_1 upto 0.5 and then decreases with the increase in Q_3/Q_1. The R_d value lies between 0.62 and 0.92. However, there is a systematic decrease in R_d value as the spacing is increased from $6D_1$ to $16D_1$. There is negligible difference between the average R_d values for the spacings of $16D_1$ and ∞. This obviously shows that there is no influence of adjoining orifice on the R_d value of test orifice beyond a spacing of $16D_1$. In Figure 7 spacing of downstream orifice on the R_d value of test orifice is indicated for an orifice diameter of 8mm. The R_d values increase with the increase in Q_3/Q_1 for all the spacings upto Q_3/Q_1 equal to 0.5 and thereafter remains asymptotic. No systematic trend in R_d values is noticed when the spacing is increased from $6D_1$ to $16D_1$. The range of R_d value is between 0.72 and 0.91. In Figure 8 the combined effect of the spacings of upstream and downstream orifices on the R_d value of test orifice is shown for 8mm diameter orifice. The R_d values increase with the increase of Q_3/Q_1 upto 0.35 and then decrease with the increase of Q_3/Q_1 for all spacings. Here again there is a systematic decrease in R_d value for the increase in spacing from $6D_1$ to $16D_1$. The range of R_d value is between 0.74 and 0.90. In Figure 3 a typical graph of R_d versus R_e is drawn for D_3/D_1 equal to 0.4, for a spacing of infinity and for a range of R_d between 20,000 and 31,000. The trend of R_d value is similar to that of R_d versus Q_3/Q_1 for the spacing of ∞. However, further experiments over an extended range of Reynolds number is necessary to draw specific conclusions with regard to variation of R_d with R_e. The studies on the influence of the angle of emergence of jet on the R_d value indicate that the pressure recovery factor is insensitive to change in the angle of emergence of jet.

5 CONCLUSIONS

The pressure recovery factor is primarily a function of discharge ratio, spacing of orifices and pipe Reynolds number. It is insensitive to diameter ratio and to angle of emergence of jet. The pressure recovery factor varies between 0.64 and 0.95 over the discharge ratio of 0.2 to 1 and is maximum at the discharge ratio equal to 0.5 for the case of single discharging orifice. The interaction of both upstream and downstream orifices on the test orifice is absent beyond a spacing of 16 times the conduit diameter from the test orifice.

6 REFERENCES

ACRIVOS, A., BABCOCK, B.D. and PIGFORD, R.L. (1959). Flow distributions in Manifolds. Chemical Engineering Science, Vol.10, pp 112-124.

BAILEY, B.J. (1975). Fluid flow in perforated pipes. Journal Mechanical Engineering Science. Vol. 17, No.6, pp 338-347.

BAJURA, R.A. (1971). A model for flow distribution in manifolds. Journal of Engineering for Power, Trans. ASME, Vol. 93, pp 7-12.

BERLAMONT, J. and VAN DER BEKEN, A. (1973). Solutions for lateral outflow in perforated conduits. Journal of the Hydraulics Division, ASCE, Vol. 99, No. HY 9, pp 1531-1549.

HORLOCK, J.H. (1956). An investigation of the flow in manifolds with open and closed ends. Journal of the Royal Aeronautical Society, Vol. 60, pp 749-753.

KUBO, T and UEDA, T. (1969). On the characteristics of divided flow and confluent flow in headers. Bulletin of JSME, Vol. 12, No. 52, pp 802-809.

McNOWN, J.S. (1954). Mechanics of manifold flow. Trans. ASCE, Vol. 119, pp 1103-1142.

OAKEY, J.R. (1933). Hydraulic losses in short tubes determined by experiments. Engineering News Record, Vol. 110, pp 717-718.

SHIVARUDRAPPA, K.B., SAKTHIVADIVEL, R., SARGUNAR, E.V.M. and NAGABHUSHANA RAO, B. (1976). Pressure recovery in manifolds. Proc. Diamond Jubilee Symp. CWPRS, Poona, India, pp A16.1-A16.17.

SOUCEK, E. and ZELNICK, E.W. (1945). Lock manifold experiments. Trans. ASCE, Vol. 110 pp 1357-1400.

VIGANDER, S., ELDER, R.A. and BROOKS, N.H. (1970). Internal hydraulics of thermal discharge diffusers. Journal of the Hydraulics Division, ASCE, Vol. 96, pp 509-527.

ZSA'K, E. (1971). Manifold flow in sub-irrigation pipes. Journal of the Hydraulics Division, ASCE, Vol. 97, pp 1737-1746.