90° Elbow Flow Meter Ⅲ

——Effect of Excess Metal on Discharge Coefficient

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(Received August 31, 1979)

The effect of wall curvature inaccuracy on the discharge coefficient of an elbow flow meter, has already been reported in the second report.

The present report examines the effect on the discharge coefficient of excess metal on the inlet and/or outlet of an elbow due to the presence of a welding joint. It is confirmed that the effect of inlet excess metal having a relative height, δ/D, of about 11 percent, attains to 10 percent or so compared with the case of without excess metal.

As one of the countermeasures for excess metal, it can be assumed that the flowmeter's function will be more effective by inserting the excess metal model into the inlet of elbow.

1. Introduction

For the study of elbow flow meters, the earliest experimental data found in the literature was that of Jacobs and Sooy1), followed by that of Addison2), Lansford3) and Kittredge4). Recently Itō, et al.5,6) made an attempt to analyze the discharge coefficient theoretically, and obtained results which agreed well with experimental values. The authors7~10) also have examined the influential factors dominating the discharge coefficient experimentally and theoretically.

When a commercial elbow welded into a pipeline is used as a flow meter, it may be predicted, from a practical point of view, that the excess metals will be recognized at the inlet and/or outlet of the elbow. The effects of excess metal on the discharge coefficients should be considerable. In this paper, the author has made an attempt to account for this problem experimentally.

The present report deals with the results obtained by using drawn-steel tubing commercial elbows having various excess metal models.

2. Nomenclature

a : radius of elbow
C_{df} : discharge coefficient, [Eq.(1)]
C_d : discharge coefficient, [Eq.(2)]
C_D : discharge coefficient, [Eq.(3)]
$\Delta C_d/C_d$: effect of discharge coefficient due to excess metal, [Eq.(4)]
D : internal diameter of elbow ($=2a$)
D_s : internal diameter of straight pipe

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H : pressure head of wall
h : differential pressure head between inside and outside of elbow-wall
L : axial length of pipe
Q : volumetric discharge
R : radius of curvature of elbow centerline, (Fig. 2)
R/a : curvature ratio of elbow
R_e : Reynolds number ($=V_mD/\nu$, ν : kinematic viscosity)
S : cross sectional area of elbow
V_m : mean velocity of flow
δ : height of excess metal
δ/D : relative height of excess metal
θ : angular position from elbow inlet

3. Definition of the discharge coefficient

The definition of the discharge coefficient of an elbow flow meter has been formulated in three ways as follows :

1) C_{df}, under a free-vortex theory,

$$C_{df}=Q\sqrt{x}/\{\sqrt{2gh}\cdot S\cdot(x-\sqrt{x^2-1})(x^2-1)\} \tag{1}$$

2) C_d, under a forced-vortex theory,

$$C_d=2Q/(\sqrt{2gh}\cdot S\cdot\sqrt{x}) \tag{2}$$

3) C_D, under a head-meter type such as an orifice,

$$C_D=Q/(\sqrt{2gh}\cdot S) \tag{3}$$

where h is pressure head differential measured between the inside and outside elbow-wall, S the cross sectional area of an elbow, Q the volumetric discharge and $x=R/a$ (curvature ratio of an elbow). In this paper, the discharge coefficient C_d defined by Eq.(2) is mainly used.

4. Experimental equipment and measuring procedure

The experimental equipment used for this study is illustrated schematically in Fig. 1. Water pumped up from a reservoir by a pump ① flows continuously through an overflow tank ②, a flux control valve ③, a rectifying tank ④, an upstream tangent ⑤, an elbow ⑥ and a downstream tangent ⑦ into a metering tank ⑧, then goes back again to the reservoir after weighing. The water temperature was measured with a mercury thermometer ⑨ during each test.

The axial length of the up and downstream tangents, ⑤ and ⑦, were taken about thirty and fifty six-times as large as their internal diameter, D_s, respectively.

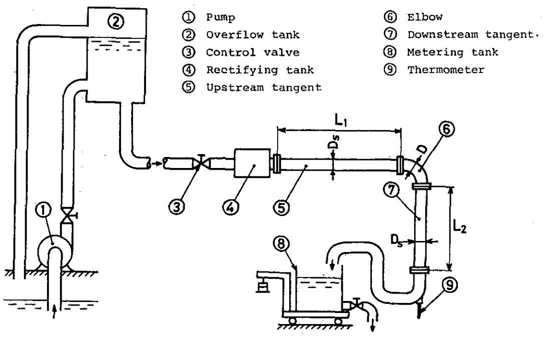


Fig. 1 Experimental equipment

The test elbows were provided with 90 deg. drawn-steel tubing commercial elbows whose radius ratios, R/a, were 1.85 and 2.93 as shown in Fig. 2. Their basic geometric parameters are summarized in Table 1. We refer to the former as the A-elbow and the latter as the B-elbow. Piezometers (0.8mm bore) were fitted on each inside and outside wall at a 45 deg. location from the inlet (at OI cross section of Fig. 2).

The excess metals due to welding were approximated by acrylic-resin-made models as shown in Fig. 3 and their typical dimensions are given in Table 2. The height of excess metal models, δ, were provided to three grades for each elbow, and the relative heights of them, δ/D, were nearly equal to each other for the same grade. Hereafter we put the individual numbers 2, 4, 6 on each grade of excess metal model as shown in Table 2.

5. Experimental results and consideration

5. 1 Discharge coefficient vs. Reynolds number

The discharge coefficients, C_d, of the drawn-steel tubing commercial elbows without excess metal are plotted against the Reynolds number, R_e, in Fig. 4. From this figure, it can be seen that the discharge coefficients, C_d, vary as increasing Reynolds numbers and tend to converge to each constant value from the "×" marking on the Reynolds number, so that the value of this Reynolds number is taken as the critical Reynolds number, R_{ec}, of the discharge coefficient of the elbow. The numerical values expressed in this figure are taken as the average value of discharge coefficients above R_{ec}.

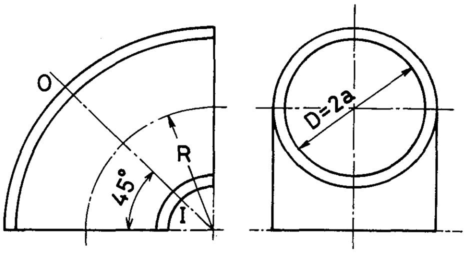


Fig. 2 90°-elbow

Table 1 Dimensions of elbow and straight pipe

Elbow				Straight pipe		
No	R/a	R mm	D=2a mm	D_s mm	L_1 mm	L_2 mm
A	1.85	50.12	54.18	52.99	1596	2966
B	2.93	77.79	53.10			

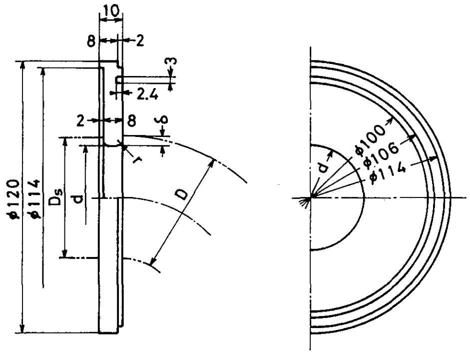


Fig. 3 Excess metal model

Table 2 Dimensions of excess metal model

Elbow			Model of excess metal				
No	R/a	D mm	No	d mm	δ mm	r mm	δ/D
A	1.85	54.18	2	50.26	1.96	1.0	3.62×10^{-2}
			4	46.26	3.96	2.0	7.31
			6	42.24	5.97	3.0	11.02
B	2.93	53.10	2	49.16	1.97	1.0	3.71
			4	45.14	3.98	2.0	7.50
			6	41.14	5.98	3.0	11.26

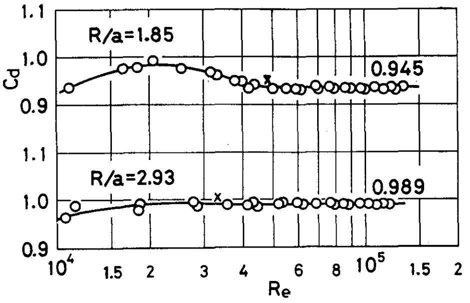


Fig. 4 Discharge coefficient against Reynolds number

5. 2 Effect of excess metal on the discharge coefficient

First of all, the author confirmed how much the excess metal on either inlet or outlet of an elbow effects the discharge coefficient of the elbow flow meter experimentally. The obtained results are shown in Fig. 5, and the above results are represented by two-dot-dash lines. The bracketed numbers denote the attaching condition of excess metal model, e.g. "(4-0)" shows such condition as the inlet of elbow having the No. 4 excess metal model (see Table 2) but the outlet not having one.

From this figure, we see that when the excess metal models are fitted at the inlet of an elbow, both discharge coefficient curves become more gentle than that of "(0-0)" and the convergence of the discharge coefficient is excellent. The average value of the discharge coefficients decreases gradually according to the increase of the excess metal height, δ, and for the case of attaching the No. 6 excess metal model, the decrease of its value is remarkable.

In the case of the outlet excess metal model, the discharge coefficients of the A-elbow ($R/a=1.85$) varies considerably and their convergence becomes worse, but for the B-elbow ($R/a=2.93$), their curves fall into approximately a single curve, in spite of changing the height of excess metal, δ.

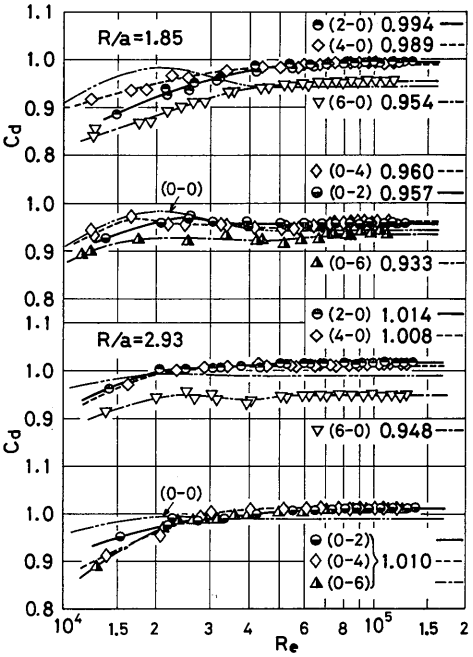


Fig. 5 Relation between C_d and R_e (excess metal being inlet or outlet of an elbow)

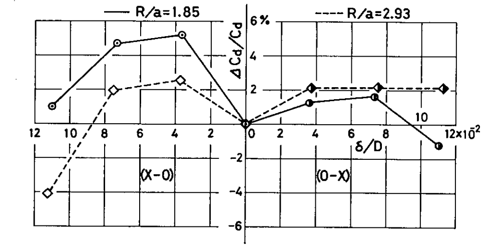


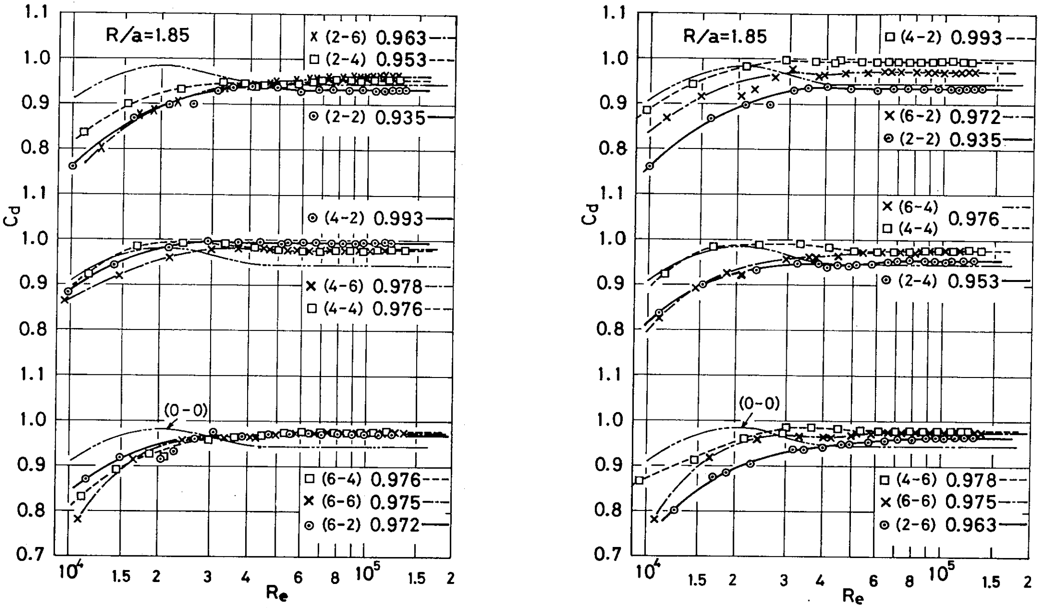
Fig. 6 Relation between $\Delta C_d/C_d$ and δ/D

Figure 6 shows the relationship between the relative height of excess metal, δ/D, and the effect on the discharge coefficient due to the excess metal, $\Delta C_d/C_d$, defined as follows:

$$\Delta C_d/C_d=(C_{di,j}-C_{d0})/C_{d0}, \qquad (i,j=2,4,6) \qquad (4)$$

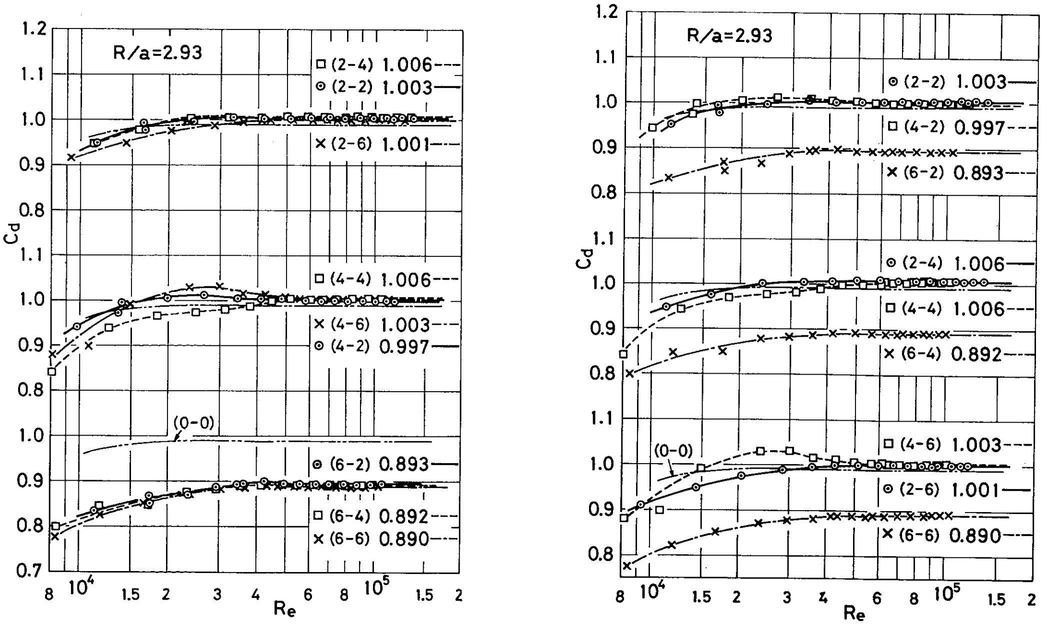
where C_{d0} stands for the mean value of discharge coefficients not having excess metal, and $C_{di,j}$ for having it, in which case the subscripts i and j denote the additional condition of excess metal as the former having it at the inlet and the latter having it at the outlet. The "(X-0)" marking in this figure shows the condition of inlet excess metal model, and the "(0-X)" that of outlet.

As obviously seen in this figure, the effect on the discharge coefficient due to excess metal, $\Delta C_d/C_d$, depends on the relative height, δ/D, and for the inlet excess metal, the effect, $\Delta C_d/C_d$, decreases with increasing δ/D, particularly for the B-elbow, the effect, $\Delta C_d/C_d$, becomes negative at $\delta/D \fallingdotseq 0.11$. When excess metal exists on the outlet for the A-elbow, the effect $\Delta C_d/C_d$, also becomes negative at $\delta/D \fallingdotseq 0.11$, but for the B-elbow the effect is maintained at an almost constant state.



(a) Inlet excess metal is constant (b) Outlet excess metal is constant

Fig. 7 Relation between C_d and R_e (excess metal being inlet and outlet of $R/a=1.85$ elbow)



(a) Inlet excess metal is constant (b) Outlet excess metal is constant

Fig. 8 Relation between C_d and R_e (excess metal being inlet and outlet of $R/a=2.93$ elbow)

In the second step, such cases were examined where the excess metals exist on both inlet and outlet of an elbow, and the obtained results are given in Figs. 7 to 9.

When the height of excess metal, δ, is kept constant at the inlet of an elbow but altered at the outlet of one, it can be seen from Figs. 7 (a) and 8 (a) that the variation of the discharge coefficient curve on each inlet excess metal grade tends to be identical approximately within 3 percent deviation.

However, when the height of inlet excess metal is altered and the height of outlet one is kept constant, it can be seen from Figs. 7 (b) and 8 (b) that the effect of inlet excess metal on the discharge coefficient appears clearly with increasing the height of inlet excess metal. Particularly, for the B-elbow ($R/a=2.93$) having the excess metal model of No. 6 at the inlet, the discharge coefficients decrease considerable and the effect extends to about 10 percent at maximum.

Consequently, let providing the excess metal model of No. 6 ($\delta/D \fallingdotseq 0.11$) on the inlet of an elbow, the discharge coefficient may be stabilized by the inlet excess metal.

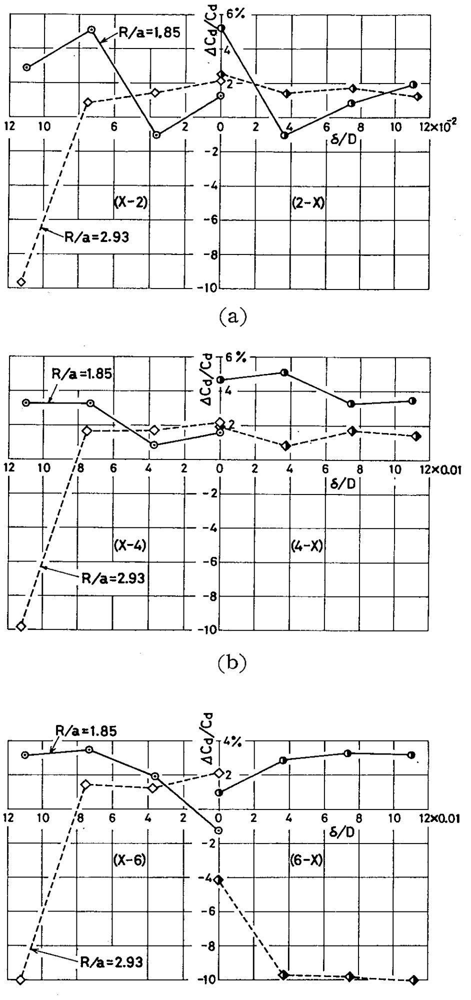


Fig. 9 Relation between $\Delta C_d/C_d$ and δ/D

Figure 9 shows the relation between the effect on discharge coefficient, $\Delta C_d/C_d$, and the relative height of excess metal, δ/D, in the same way as Fig. 6. From this figure, the effect of the No. 6 inlet excess metal model of the B-elbow ($R/a=2.93$) becomes negative : i.e. this means an increase of the differential pressure head, h, measured between the inside and outside elbow-wall, thus the discharge coefficient is reduced.

6. Conclusion

When a commercial elbow welded into a pipeline is used as a flow meter, the effect on the discharge coefficient, $\Delta C_d/C_d$, due to the excess metal which arises at the inlet and/or outlet by welding joint, appears clearly with increasing the relative height of excess metal, δ/D. In particular, when the No. 6 excess metal model ($\delta/D \fallingdotseq 0.11$) is inserted into the inlet of the B-elbow ($R/a=2.93$), the effect on the discharge coefficient becomes negative.

When the height of excess metal, δ, is kept constant at the inlet of an elbow, the variation of the discharge coefficient tends to be identical within about 3 percent deviation, in spite of changing the height of outlet excess metal as $\delta/D \fallingdotseq 0.04$ to 0.11, and it can be seen that the inlet excess metal acts as the stabilizer of the discharge coefficient.

Hence, it is shown that if an elbow welded into a pipeine is used as a flow meter, this meter's function may be more effective by attaching the excess metal model of $\delta/D \fallingdotseq 0.11$ into the inlet of an elbow.

Acknowledgements

The author wishes to express his thanks to Professor M. Murakami and Professor H. Yamada for encouragement.

This work was supported by the Research Funds of Chubu Institute of Technology.

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