Acta Technica 62 (2017), No. 4A, 801–808

Problems and solutions in measuring local resistance coefficient

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Abstract. There are many problems in old experiment for the local resistance coefficient, such as inconvenience of water inflow and outflow of the tanks, water ejection from the top of piezometric tubes, large measurement error, wrong conclusions. Through the observation and analysis of students' experiment process, the experiment device was reformed. The open extent of the inflow and outflow valves must be consistent before experiment. When the experiment device is full of water, air in the hose is expelled at first, and then to measure data. The measuring point was moved forward a certain distance before the abrupt interface for determination of the local resistance coefficient where flow section expanded suddenly. With these improvements, those problems were solved.

Key words. Experiment for local resistance coefficient, local head loss,local resistance coefficient.

1. Problems and causes analysis of old measurement experiment for local resistance coefficient

1.1. Old experiment device and its measuring principle

1.1.1. Old experiment device The old experiment device in our school is shown in figure 1. It can simulate the sudden expansion and narrowness of the tube and water flowing through valves and other pipe fittings. The main content of this experiment:

There are three pipelines in the old experiment device, which were marked as piping I, pipe II and pipe III in turn. There were six holes (1˜6) in pipe I for measuring local resistance coefficient where flow section changes sharply. There were four holes (7˜10) in pipe II and four holes (11˜14) in pipe III for measuring local resistance coefficient of pipeline valves. The ball valves in the middle were used for testing. Two cut-off valves for controlling water flowing in and out were located at both ends of the pipeline. The profile of experiment device is shown in figure 2.

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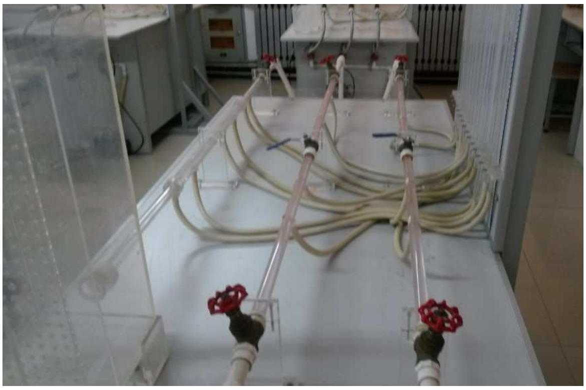

Fig. 1. Photograph of experiment device

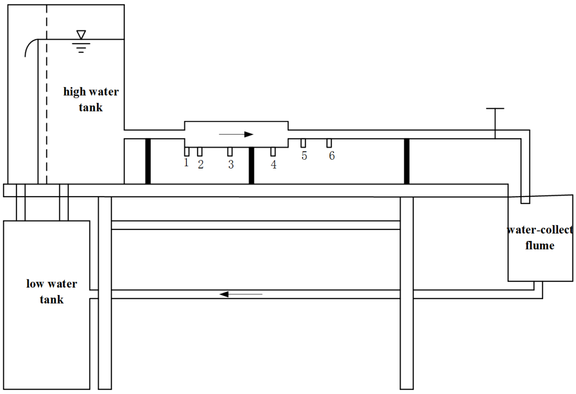

Fig. 2. Profile of old experiment device

The diameter of the pipe I was expanded from D1=10mm to D2=19mm, then decreased to 10mm. The diameter of pipe II is D3=14mm, and diameter of pipe III is D4=10mm. The water temperature was 20, and the coefficient of kinematic viscosity of the water was $\nu = 1.007 \times 10^{-6} \mathrm{m}^2/\mathrm{s}$.

1.1.2. experiment procedure Referring to measurement method in hydraulics experiments given by Li Ming and Wang Le et al Zhang Yanjie, Li Jiachun [1], and Zhang Zhichang [2] et al, the procedure of this experiment were as follows:

(1)fill the constant-pressure tank placed aloft and make it overflow.

(2)switch on the wash-out valve of the pipeline I, and close the feed valve of pipeline II and pipeline III. Adjust feed valve so that it has 5 different degrees of opening. Each time the flow was stable, the water volume in a period of time was measured by measuring glass, and the time was measured by a stopwatch. Measure and record the piezometric readings of holes, h_1, h_2, h_3, h_4, h_5, h_6 for hole 1, 2, 3, 4, 5, 6. Fill in table 1.1 with the above data.

(3)Open the wash-out valve of the pipeline II, and close the feed valve of pipeline I and pipeline III. Unscrew the test valve at three different degrees of opening:

30, 45 and fully open. The water volume in a period of time was measured by measuring glass, and the time was measured by a stopwatch. Measure and record the piezometric readings of holes, h_7, h_8, h_9, h_{10} for hole 7, 8, 9, 10. Fill in table 1.2 with the above data.

(4)Open the wash-out valve of the pipeline III, and close the feed valve of pipeline I and pipeline II. Unscrew the test valve at three different degrees of opening: 30?, 45? and fully open. The water volume in a period of time was measured by measuring glass, and the time was measured by a stopwatch. Measure and record the piezometric readings of holes, h_{11}, h_{12}, h_{13}, h_{14} for hole 11, 12, 13, 14. Fill in table 1.3 with the above data.

1.1.3. experiment principle (1)local resistance coefficient where the flow section expanded and narrowed suddenly

According to the measured data and the energy equation of the actual liquid [3],[4], the local resistance coefficient is calculated. Because the distance between section 1-1 and section 2-2 is very short, so the water head loss between the two sections was ignored, and the local water head loss $\boldsymbol{h}_m$ was considered only.

$$h_m = \left(z_1 + \frac{p_1}{\rho g} + \frac{\alpha_1 v_1^2}{2g}\right) - \left(z_2 + \frac{p_2}{\rho g} + \frac{\alpha_2 v_2^2}{2g}\right) = \left(z_1 + \frac{p_1}{\rho g}\right) - \left(z_2 + \frac{p_2}{\rho g}\right)$$

Because section 1-1 was the critical interface where the diameter of pipe varies, so v_1=v_2.

$$h_m = \left(z_1 + \frac{p_1}{\rho g}\right) - \left(z_2 + \frac{p_2}{\rho g}\right)$$

ΔR_{1-2} was used to represent the height difference of water in piezometric tube at both ends of pipe, so $\Delta R_{1-2} = h_m$.

$h_m = \xi \frac{v^2}{2g} v = \frac{Q}{A} = \frac{4Q}{\pi D^2} h_m = \xi \frac{v^2}{2g} = \xi \frac{8Q^2}{\pi^2 g D^4} \Rightarrow \xi = \frac{\pi^2 g D^4 h_m}{8Q^2} = \frac{\pi^2 g D^4 \Delta R_{1-2}}{8Q^2}$

Reynolds number $Re = \frac{vD}{\nu} = \frac{4Q}{\pi D \nu}$

So the local resistance coefficient ξ and the corresponding Reynolds number **Re** can be calculated by experimental data and above formulas. Fill in table 1.2 with the result of calculation.

(2)local resistance coefficient of pipeline valves

In order to eliminate the influence of the resistance along the pipeline , two pressure differences, $\Delta h_1 = h_7 - h_{10}$ and $\Delta h_2 = h_8 - h_9$, were calculated according to the measured data. The pipe diameter was D_3=14mm. Then to calculate the resistance loss caused by the valve, Δh_2.

$$\Delta R = 2\Delta h_2 - \Delta h_1$$

In the same way, the formula of local resistance coefficient of pipeline valves can be obtained by using the energy equation of the actual liquid.

$$\xi = \frac{2g\Delta R}{V^2} = \frac{\pi^2 g D_3^4 \Delta R}{8Q^2}$$

So the local resistance coefficient ξ can be calculated by experimental data and above formulas. Fill in table 1.3 with the result of calculation.

1.2. Problems and causes analysis of old measurement experiment for local resistance coefficient

1.2.1. Problems in old tests Table 1.1, table 1.2, and table 1.3 are experiment data and computation results. In table 1.2, some energy losses and local resistance coefficients were negative. This result indicates that the energy of the water in the pipe has not decreased, but increased, where the pipe diameter suddenly increases. Obviously, it does not accord with the actual liquid energy change and energy equation [5],[6]. The local resistance coefficients were also quite different from those in the design manual. As shown in table 1.3, the measured coefficients were quite different from the calculated results, and the error is beyond the error range. The error of the local resistance coefficient obtained by experiment at the valve was too large.

Table 1.1 Experiment data

	V ($10^{-4}m^3$)	T (s)	Q ($10^{-6}m^3/s$)	h_1	h_2	h_3	h_4
1	8.50	7.62	112.0	0.332	0.365	0.362	0.361
2	8.00	8.02	99.8	0.355	0.384	0.382	0.385
3	7.50	8.72	86.0	0.415	0.431	0.425	0.424
4	7.30	12.54	58.2	0.485	0.486	0.484	0.480
5	4.00	27.10	14.8	0.515	0.516	0.517	0.516

Table 1.2 Calculating data of local resistance coefficient

	ΔR_{1-2}	ξ	Re	ΔR_{4-5}	ξ	Re	ΔR_{5-6}
1	-0.033	-4.23	7457.07	0.036	0.35	14168.0	0.011
2	-0.029	-4.68	6644.78	0.121	1.50	12624.7	0.004
3	-0.016	-3.43	5725.97	0.690	1.15	10879.0	0.012
4	-0.001	-0.22	3875.01	0.020	0.73	73623.0	0.015
5	-0.001	-4.00	985.40	0.003	1.69	1872.2	0.001

Table1.3 Experiment data

pipe number	valve opening	V 10^{-4}m^3	T s	Q 10^{-6}m^3/s	v m/s	h_7 (h_{11})	h_8 (h_{12})	h_9 (h_{13})	h_{10} (h_{14})
pipe	30	6	17.75	33.803	0.220	1.055	1.052	0.272	0.268
	45	6	13.38	44.843	0.291	0.475	0.472	0.339	0.335
	fully open	6	12.31	48.741	0.317	0.377	0.377	0.365	0.360
pipe	30	8	31.75	25.197	0.321	1.200	1.199	0.175	0.157
	45	8	19.75	40.506	0.516	0.550	0.544	0.222	0.212
	fully open	8	17.94	44.593	0.568	0.275	0.270	0.239	0.230

1.2.2. Causes analysis of old measurement experiment for local resistance coefficient Through observation and analysis, the reasons for the three main problems mentioned above were as follows:

(1)water inflow and outflow were inconvenient

As the entire experimental device was purchased integrally, the equipment was installed directly on the ground floor. The water inflow and drainage of the experimental device were not connected with the water supply system and the drainage system of the laboratory, which resulted in much inconvenience to the experiment.

(2)water spurted from the top of the piezometric tube.

The main reason is that students did not accurately control the opening of the pipeline valves for inflow and outflow. When the opening of inflow valve was wider than that of outflow valve, the head of the piezometric pipe was too high at the testing point. As a result, water spurted from the top of the piezometric tube.

It was completely wrong that the local water head loss and the local resistance coefficient were negative. Next, it is proved theoretically. This part of fluid between the 1-1 section and the 2-2 section was chosen as the object of study. According to the energy equation of actual liquid, we can arrive at the conclusion:

$$z_1 + \frac{p_1}{\rho g} + \frac{\alpha_1 v_1^2}{2g} = z_2 + \frac{p_2}{\rho g} + \frac{\alpha_2 v_2^2}{2g} + h_m \tag{1}$$

Use energy equation of liquid,

$$p_1 A_1 - p_2 A_2 = \frac{\rho g Q_v}{g}\left(\alpha_{02} v_2 - \alpha_{01} v_1\right) \tag{2}$$

$Q_v = v_2 A_2 = v_1 A_1$ For turbulent flow, $\alpha_1 = \alpha_2 = 1$, $\alpha_{01} = \alpha_{02} = 1$
$h_m = \left(1 - \frac{A_1}{A_2}\right)^2 \frac{v_1^2}{2g} = \xi_1 \frac{v_1^2}{2g}$ or $h_m = \left(\frac{A_2}{A_1} - 1\right)^2 \frac{v_2^2}{2g} = \xi_2 \frac{v_2^2}{2g}$

So the local resistance coefficient where the flow section expanded suddenly is $\xi_1 = \left(1 - \frac{A_1}{A_2}\right)^2$ or $\xi_2 = \left(\frac{A_2}{A_1} - 1\right)^2$.

Obviously$\xi_1 > 0$, $\xi_2 > 0$. It can be seen that some measured values were essentially different from theoretical values, so they were considered wrong conclusions.

The above wrong conclusions were mainly caused by the following reasons:

(1)The energy equation of the actual liquid was used to calculate the local resistance coefficient. The section must be in the position of uniform flow or gradually varied flow. The energy equation is applicable on this condition. The hole 1 of the experimental device was arranged at the place where the size of the pipe section changed suddenly. In other words, the water flowing through cross section 1-1 is rapidly varied flow, not gradually varied flow, not uniform flow. The rapidly varied flow does not meet the conditions of the energy equation. This is an important reason for the wrong conclusion.

(2)The flow velocity $\boldsymbol{v}$ used to calculate the local resistance coefficient is the mean flow velocity of section. For the section 1-1 in experiment, because of the inertia force, the turning angle of fluid can not be the same as that of pipe. Thus the solid-liquid separation zone appeared at the interface. Then the backwater of the rear area formed vortex. It cycled in this way [7],[8]. As shown in figure 2.3, it is obvious that the distribution of flow velocity across the section is very irregular. It is sure to bring great deviation that the local resistance coefficient was calculated simply by using the mean flow velocity of the section 1-1.

The combined effect of the above three aspects was the fundamental reason for the negative value of local energy loss and local resistance coefficient where the flow section expanded suddenly.

2. Solution to the problem of experiment

(1)Improve the inflow and outflow of the experiment device

In order to facilitate the water supply and drainage of water tank, a water inflow device was installed at the top of the low water tank. The holes were added at the top and bottom of the water tank, and pipes were installed. The water inlet of the water tank was connected to the water supply system of the building. A float valve was installed at the end of the inlet pipe. The drainage of the tank was connected to the drainage system of the building. Below the inlet, 2.5 times the diameter of the inlet pipe, overflow device was added, including overflow hole and pipe. The diameter of overflow pipe was larger than that of inlet pipe, and the overflow pipe was connected with the drainage system of the building to avoid the water overflow to the indoor ground [9],[10].

(2)prevent water ejecting from the top of piezometric tube

Before the experiment, it was specially emphasized to students that inflow valve and outflow valve should be opened at the same extent in the experiment to avoid water ejecting from the top of piezometric pipe.

(3)method for reducing the error

Students were asked to empty the air in the hose first and then begin experiment after completing the water of experiment device. the local resistance coefficient. The hole 1 used to measure local resistance coefficient was moved forward, let it leave the location of interface mutation. In this way, the new section 1-1 met the uniform flow condition. The area of the flow section is consistent with that of the pipe. There is no solid-liquid separation or vortex at the section. After repeated measurements used by the reformed experiment device, the measurements no longer showed negative values, and the measured data was more accurate.

Table 2.1 Experiment data

	V $10^{-4}m^3$	T	Q $(10^{-6}m^3/s)$	h_1	h_2	h_3	h_4
1	0.680	10.00	68.000	0.505	0.502	0.501	0.501
2	0.800	10.00	80.000	0.425	0.421	0.420	0.419
3	0.410	5.00	82.000	0.405	0.401	0.398	0.397
4	0.390	5.00	78.000	0.440	0.436	0.435	0.435
5	0.450	5.00	90.000	0.360	0.355	0.354	0.353

Table 2.2 Calculating data of local resistance coefficient

	ΔR_{1-2}	ξ	Re	ΔR_{4-5}	ξ	Re	ΔR_{5-6}
1	0.003	1.022	4525.2	0.018	0.471	8597.9	0.001
2	0.004	0.985	5323.7	0.026	0.491	10115.1	0.003
3	0.004	0.937	5456.8	0.027	0.485	10368.0	0.016
4	0.004	1.036	5190.7	0.025	0.497	9862.2	0.007
5	0.005	0.973	5989.2	0.033	0.493	11379.5	0.055

Table 2.3 Experiment data

pipe number	valve opening	V $10^{-4}m^3$	T s	Q $10^{-6}m^3/s$	v m/s	h_7 (h_{11})	h_8 (h_{12})	h_9 (h_{13})	h_{10} (h_{14})
pipe	30	3.2	5.22	61.303	0.399	1.200	1.200	0.170	0.170
	45?	3.5	5.15	67.961	0.441	0.910	0.910	0.240	0.230
	fully open	4.5	5.34	84.270	0.547	0.395	0.390	0.350	0.340
pipe	30	2.5	5.28	47.348	0.603	1.550	1.540	0.305	0.295
	45	3.0	5.08	59.055	0.752	1.080	1.070	0.550	0.530
	fully open	3.5	5.25	66.667	0.849	0.790	0.780	0.718	0.695

3. Conclusion

(1)The holes were added at the top and bottom of the water tank, and pipes were installed. the inflow and outflow of experiment devices become more convenient, and the water overflow to the indoor ground is avoided.

(2)The hole 1 used to measure local resistance coefficient was moved forward, let it leave the location of interface mutation. In this way, the measurements no longer show negative values.

(3)Before the experiment, it is specially emphasized to students that inflow valve and outflow valve should be opened at the same extent in the experiment and that the air in the hose must be empty first. So, the data error is reduced.

After the transformation of measuring device, it not only made the operation convenient, but also made the measurement data more reasonable, so as to achieve the purpose and requirement of the experiment.

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This paper got funding from the following government departments.

1. Department of Science and technology of Henan Province (122102310313)
2. Department of Science and technology of Henan Province (162102310113)
3. Education Department of Henan Province (18A560017)

Received November 16, 2016