Physical Modeling to Determine Head Loss at Selected Surcharged Sewer Manholes

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Technical Memorandum for Reporting the Manhole Head Loss of 4-inch Model Scale Pipes

Technical Memorandum

Project title: Physical Modeling to Determine Head Loss at Selected Surcharged Sewer Manholes

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This memorandum summarizes the results of energy loss measured in a physical model with 4-inch model scale pipes and a 8-inch manhole base. The head loss coefficients for flow configurations of straight, T junction, cross and 90-degree bend are reported. The manhole head loss is also reported as the equivalent energy loss due to friction using the concept of equivalent pipe length. This information is useful for the numerical pipeline modeling.

A procedure to determine the head-loss coefficient was given in the previous report. A figure showing the energy grade lines either along the inlet lines or the outlet line is again presented here for reference (Fig. 1). The energy loss associated with the flow in and out of the manhole is described by the energy equation. The energy equation along the in-line main pipe is expressed as

$$h_m + \frac{V_m^2}{2g} = h_o + \frac{V_o^2}{2g} + K_m \frac{V_o^2}{2g}, \qquad (1)$$

where h_m and h_o are the piezometric heads for the inlet main line and the outlet line, respectively. V_m is the average velocity in the inlet main pipe and V_o denotes the average outflow velocity. K_m is defined as the head loss coefficient due to flow in the in-line main pipe. Similarly, following the lateral inflow from the side pipes to the outlet pipe, the energy equation becomes

$$h_a + \frac{V_a^{\ 2}}{2g} = h_o + \frac{V_o^{\ 2}}{2g} + K_a \frac{V_o^{\ 2}}{2g} , \qquad (2)$$

where h_a is the piezometric heads for the lateral pipe. V_a is the average velocity in the lateral pipe. K_a is the associated head loss coefficient related to the lateral inflow. If an additional side flow is considered, the head loss coefficient of K_b is introduced.

The head loss coefficients are determined from the measured data. The values of K_m, K_a, and K_b for different flow configurations under various flow rates are shown in Table 1 and Table 2. The results presented have been scaled up to the prototype situation with 1: 6 scaling factor. Therefore, the results are for the 24-inch pipe. In order to put these data into practical use for numerical modeling, the equivalent pipe length for the inflow pipes under different flow condition is introduced and included in Table 1 and Table 2.

The manhole head loss can be transferred to the equivalent friction loss due to the existence of additional pipe length. This additional pipe length is defined as the equivalent pipe length. The equivalent pipe length will be added or subtracted from the actual designed pipe length to reflect the effect of the manhole head loss in the numerical pipeline modeling. However, the actual pipe length remains unchanged. A schematic diagram of showing the actual pipeline and manhole system is given in Fig. 2(a). The setup of pipeline system by including the equivalent pipe length for numerical modeling is shown in Fig. 2(b) for comparison. L_m and L_a (or L_b) represent the equivalent pipe length for the inlet main line and lateral, respectively. To transfer the manhole head loss to an equivalent pipe length, we use the Darcy-Weisbach equation

$$h_L = f \frac{L}{D} \frac{V^2}{2g} , \qquad (3)$$

where, h_L is the general term for energy loss due to friction, f is the friction coefficient, L is a typical pipe length and D is the pipe diameter. After combining equation (3) with the

Chezy's formula and the Manning's equation, the friction coefficient is related to the Manning's roughness coefficient, n, as (British system)

$$f = 5.75 \frac{gn^2}{D^{1/3}} \tag{4}$$

The equivalent pipe length for the manhole head loss along the main line can be determined by using

$$K_m \frac{V_o^2}{2g} = 5.75 \frac{gn^2}{D^{1/3}} \frac{L_m}{D} \frac{V_m^2}{2g} . \tag{5}$$

Therefore, the equivalent pipe length for the main line inflow pipe is

$$L_m = \frac{D^{4/3}}{5.75\ g\ n^2} \frac{V_o^2}{V_m^2} K_m \tag{6}$$

Accordingly, the equivalent pipe length for the side inflow pipe is determined by

$$L_a = \frac{D^{4/3}}{5.75\ g\ n^2} \frac{V_o^2}{V_a^2} K_a \tag{7}$$

The equivalent pipe lengths L_m, L_a ,and L_b for different pipe combinations and flow rates are presented at last three columns in Table 1 (for n =0.015) and Table 2 (for n= 0.013).

After analyzing all the measurements for the 4-inch lines at the main, both laterals, and the outlet, we obtain two empirical formula to determine the head loss coefficient for the main line, K_m , and lateral, K_a (or K_b). These equations are

$$K_m = 1.1\ (q_a - q_b)^2\ q_m - 0.4\ (\ q_m + 1.75)\ (q_m\ - 1) \tag{8}$$

$$K_a = 0.9 + 0.52\ (\ q_b - q_a + 0.1)^2 - q_m\ (\ 1.2 q_m\ + 0.7 q_b - 0.7\ q_a + 0.6) \tag{9}$$

As described in previous section, K_m and K_a are the head loss coefficients referenced to outlet velocity head ($\frac{V_o^2}{2g}$) for the main line " m" and lateral " a", respectively. q_m, q_a, and q_b are the flow fractions in the main line and laterals "a" and "b" respectively. That is $q_m = \frac{Q_m}{Q_o}$, etc. For K_b, use the K_a formula with q_a and q_b interchanged.

The error distribution of the data analysis is presented in Fig. 3 to demonstrate the reliability of the data presented. From Fig. 3, it is noted most of the data obtained are located within fit error of 0.05 and -0.05.

Work continues as described in the proposal. The head loss measurements for the 3-inch pipelines are in progress and will be completed in March. We will submit a report to summarize the head loss coefficients for the 3-inch pipelines as well.

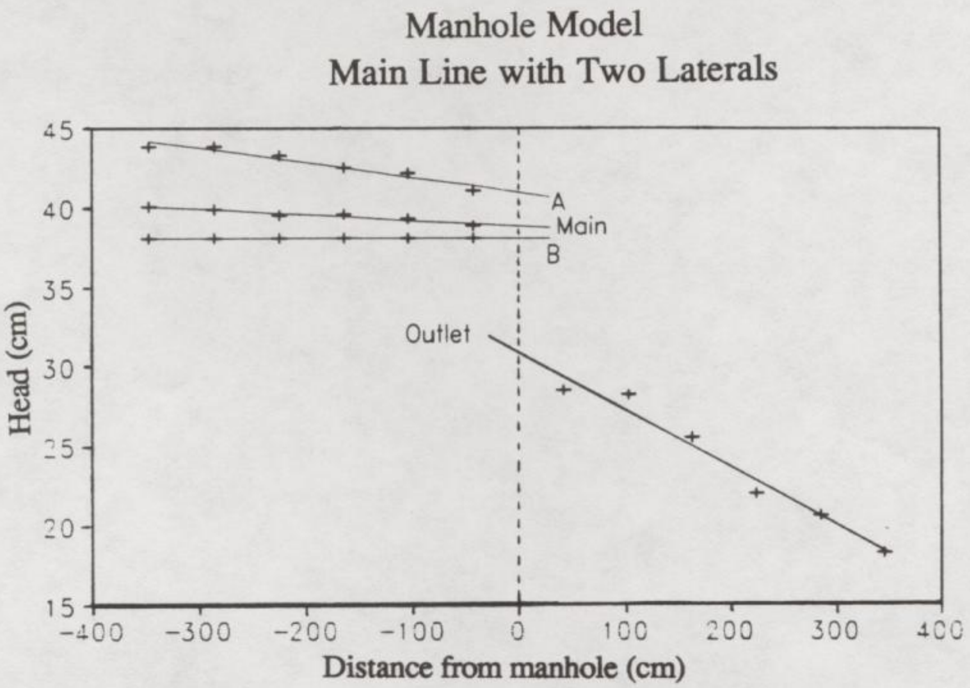

Fig. 1. Typical energy grade line plots.

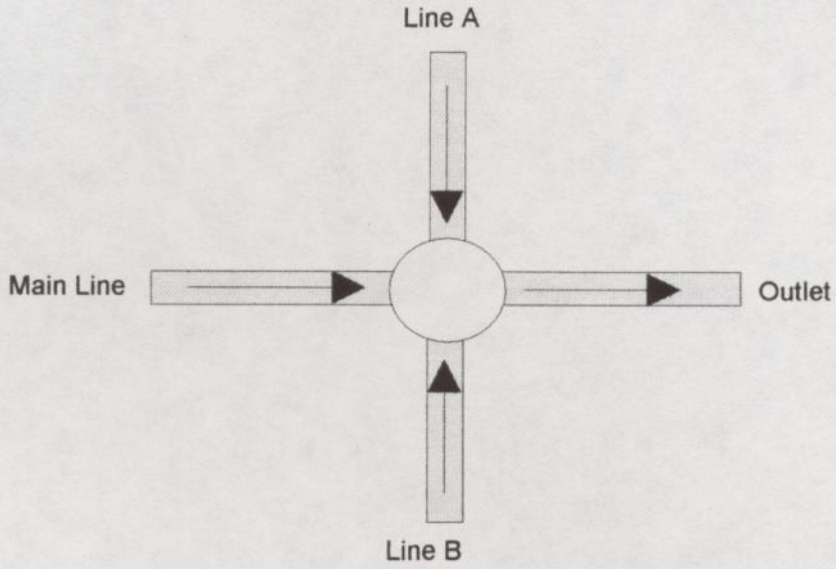

Fig. 2(a). Schematic diagram of an actual pipeline and manhole system.

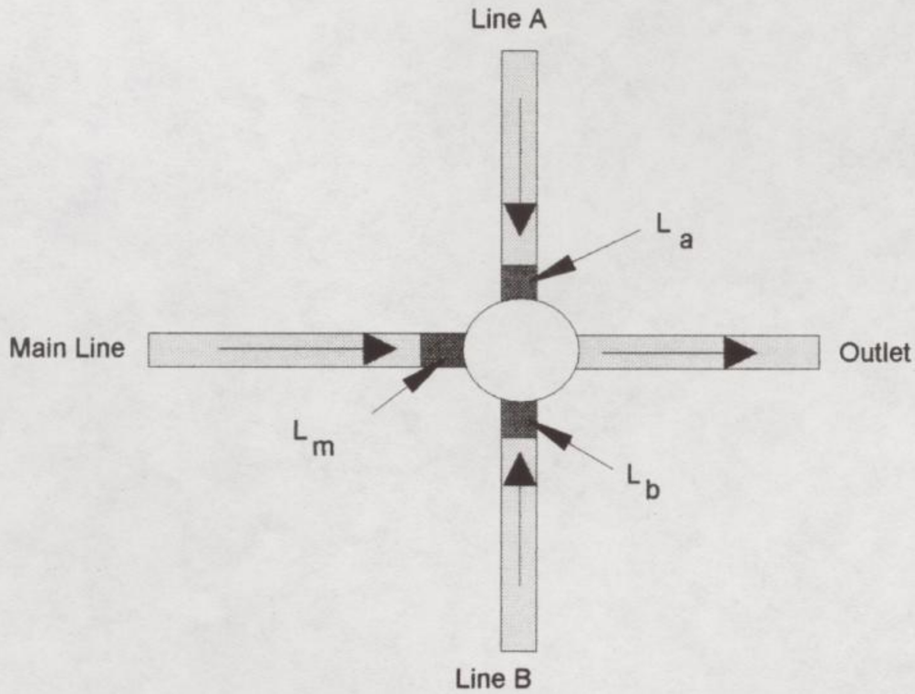

Fig. 2(b). Transferred pipeline system by including the equivalent pipe length for numerical modeling

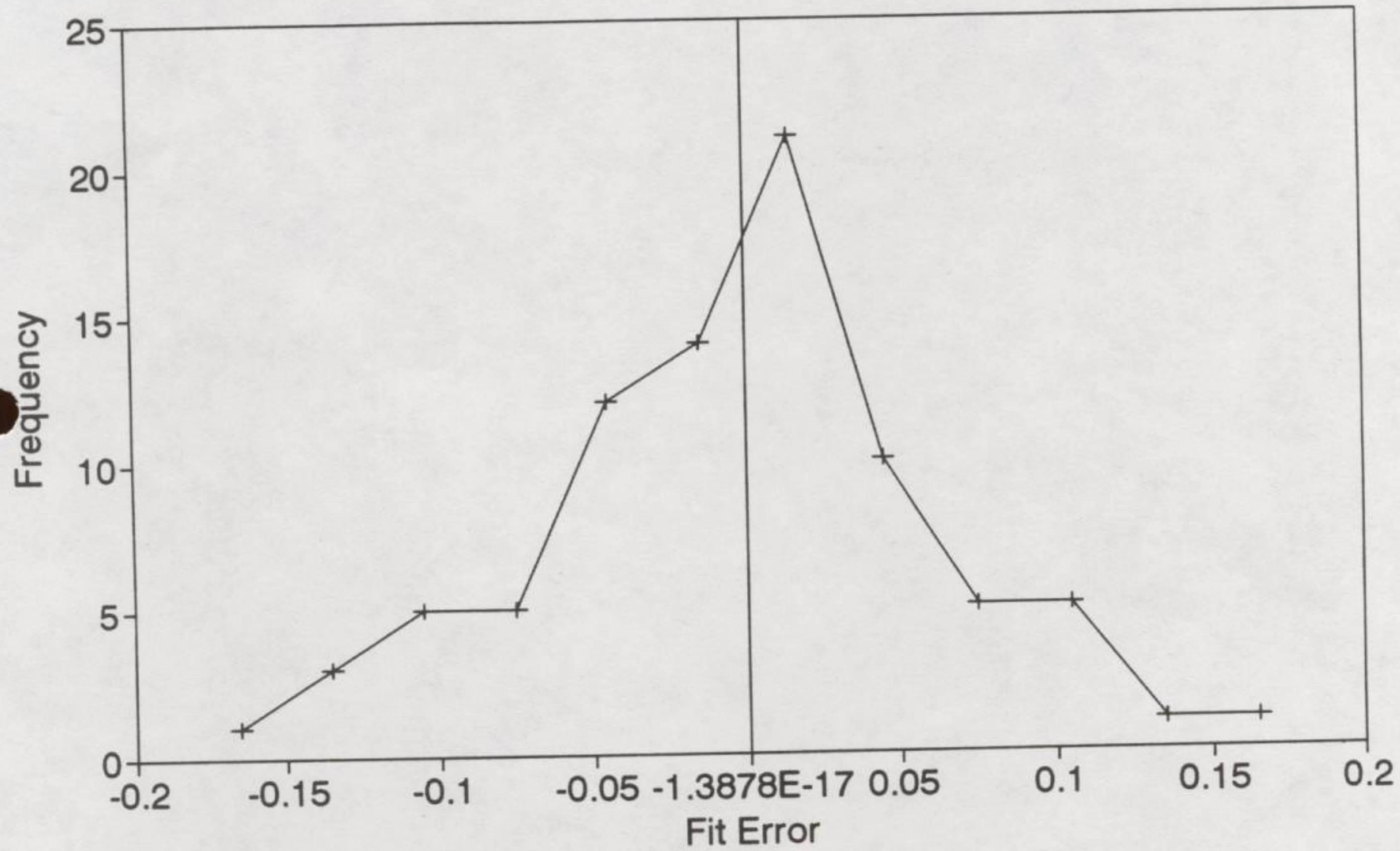

Fig. 3. Distribution of fit errors.

Table 1. Manhole head loss coefficients and equivalent pipe length for different pipe configurations at various flow rates (n= 0.015).

Measured Data, scaled up to 24 inch pipe with n = 0.015

Flow Velocities (ft/s)			K Values			Equivalent Pipe Length (ft)		
Vm	Va	Vb	Km	Ka	Kb	Lm	La	Lb
Main Line with Two Perpendicular Laterals								
9.5	3.0	2.4	0.360	0.060	0.037	53.2	90.7	87.4
6.1	5.0	3.7	0.551	0.479	0.455	198.3	250.7	440.4
6.0	5.9	3.2	0.511	0.462	0.414	193.2	183.8	568.0
5.8	4.2	4.5	0.583	0.520	0.517	220.4	374.1	325.5
4.0	4.6	5.2	0.587	0.589	0.610	422.3	308.3	255.6
3.7	5.5	4.6	0.635	0.667	0.635	527.0	252.2	352.8
3.7	4.0	6.1	0.643	0.631	0.691	533.6	453.9	206.4
3.3	3.0	7.5	0.627	0.615	0.753	658.6	768.8	156.2
2.6	9.4	2.6	0.691	0.851	0.700	1290.3	125.7	1307.1
2.6	7.8	4.3	0.619	0.768	0.642	1155.8	165.4	461.8
2.6	5.9	5.9	0.644	0.714	0.704	1202.5	257.0	253.4
1.2	8.9	5.2	0.726	0.884	0.829	6863.0	159.0	433.9
Main Line with One Perpendicular Lateral								
10.7	2.5		0.213	-0.275		19.6	-460.9	
10.4	3.5		0.194	-0.196		20.9	-189.7	
9.9	2.3		0.168	-0.315		15.5	-527.9	
9.5	3.9		0.326	0.012		39.1	8.6	
8.7	4.7		0.395	0.204		56.6	100.8	
7.1	6.6		0.664	0.611		148.6	160.4	
7.0	5.3		0.554	0.433		103.2	141.7	
5.2	6.6		0.682	0.765		213.1	147.6	
4.3	8.3		0.637	0.809		333.4	112.4	
4.1	9.1		0.672	0.853		423.1	108.4	
3.9	8.6		0.701	0.931		441.3	118.3	
3.0	8.2		0.853	1.048		707.9	119.0	
2.0	10.4		0.794	1.150		1876.4	98.6	
1.7	11.5		0.829	1.279		2967.7	102.2	
Main Line Only								
12.3			0.097			5.9		
9.7			0.027			1.6		
7.7			0.031			1.9		
Two Laterals, No Main Line								
	10.3	1.1		1.145	1.318		85.5	7973.9
	9.3	3.6		1.127	1.186		131.5	915.2
	9.0	5.3		1.026	1.105		156.4	488.3
	7.3	7.0		0.804	0.789		187.0	198.8
90 degree Bend								
	14.3			1.286			77.8	
	10.7			1.285			77.7	
	8.8			1.367			82.7	
	8.8			1.238			74.9	
	6.5			1.295			78.3	
	5.4			1.292			78.2	
	4.5			1.388			84.0	
	3.0			1.455			88.0	

Table 2. Manhole head loss coefficients and equivalent pipe length for different pipe configurations at various flow rates (n= 0.013).

Measured Data, scaled up to 24 inch pipe with n = 0.013

Flow Velocities (ft/s)			K Values			Equivalent Pipe Length (ft)		
Vm	Va	Vb	Km	Ka	Kb	Lm	La	Lb
Main Line with Two Perpendicular Laterals								
9.5	3.0	2.4	0.360	0.060	0.037	70.8	120.9	116.5
6.1	5.0	3.7	0.551	0.479	0.455	264.2	334.0	586.8
6.0	5.9	3.2	0.511	0.462	0.414	257.4	244.8	756.7
5.8	4.2	4.5	0.583	0.520	0.517	293.7	498.4	433.6
4.0	4.6	5.2	0.587	0.589	0.610	562.6	410.7	340.5
3.7	5.5	4.6	0.635	0.667	0.635	702.1	336.0	470.0
3.7	4.0	6.1	0.643	0.631	0.691	710.9	604.7	275.0
3.3	3.0	7.5	0.627	0.615	0.753	877.4	1024.2	208.1
2.6	9.4	2.6	0.691	0.851	0.700	1719.0	167.5	1741.4
2.6	7.8	4.3	0.619	0.768	0.642	1539.9	220.4	615.3
2.6	5.9	5.9	0.644	0.714	0.704	1602.0	342.3	337.6
1.2	8.9	5.2	0.726	0.884	0.829	9143.1	211.8	578.0
Main Line with One Perpendicular Lateral								
10.7	2.5		0.213	-0.275		26.2	-614.0	
10.4	3.5		0.194	-0.196		27.8	-252.8	
9.9	2.3		0.168	-0.315		20.6	-703.3	
9.5	3.9		0.326	0.012		52.1	11.5	
8.7	4.7		0.395	0.204		75.4	134.2	
7.1	6.6		0.664	0.611		197.9	213.7	
7.0	5.3		0.554	0.433		137.4	188.7	
5.2	6.6		0.682	0.765		283.9	196.6	
4.3	8.3		0.637	0.809		444.1	149.7	
4.1	9.1		0.672	0.853		563.6	144.4	
3.9	8.6		0.701	0.931		587.9	157.6	
3.0	8.2		0.853	1.048		943.1	158.5	
2.0	10.4		0.794	1.150		2499.9	131.4	
1.7	11.5		0.829	1.279		3953.7	136.2	
Main Line Only								
12.3			0.097			7.8		
9.7			0.027			2.2		
7.7			0.031			2.5		
Two Laterals, No Main Line								
	10.3	1.1		1.145	1.318		113.9	*******
	9.3	3.6		1.127	1.186		175.2	1219.3
	9.0	5.3		1.026	1.105		208.4	650.6
	7.3	7.0		0.804	0.789		249.1	264.9
90 degree Bend								
	14.3			1.286			103.7	
	10.7			1.285			103.6	
	8.8			1.367			110.2	
	8.8			1.238			99.8	
	6.5			1.295			104.4	
	5.4			1.292			78.2	
	4.5			1.388			111.9	
	3.0			1.455			117.3	