Local head loss consideration in hydraulic modeling of sewer networks

Sima Safarkhani[1], Siavash Katebizaki[2]

[1] Civil engineering department, Sharif University of Technology, Tehran, Iran
[2] Water engineering department, I.K.I.University, Qazvin, Iran

---***---

Abstract – ***Values of Manning's roughness may be known by engineers familiar with the sewer system. Otherwise, they may be estimated from tables in many engineering references (e.g., Chow, 1959; ASCE-WPCF, 1969) as a function of the construction material and sewer conditions. The value may be adjusted to account for losses not considered in the routing procedure (e.g., head losses in manholes or other structures, roots, obstructions). However, the flow routing is relatively insensitive to small changes in Manning's n [17].***
Head loss at manhole structures depends on many factors such as manhole dimensions, number of inverts and outlets, discharge rate and invert and outlet level and should be definitely considered in sewer network calculations. There are some recommendation for taking these kind of head losses into accounts [3,12]. But, how much increase in the roughness coefficient should be considered to cover manhole's head losses as well. There are different methods for local head loss calculation in manhole structures.
In this research, 4 different networks have been investigated (using SewerCAD software) which 2 of them belong to secondary and main sewer network of a steep area in Tabriz city and the other 2 belong to secondary and main sewer network of a mild slope area in Eghbalieh city.
The final recommendations are 2% increase in manning coefficient for simple networks with less junctions to 5% increase in manning coefficient in more complicated networks with lots of junctions and slope variations.

Key Words: *Local head loss, Pipeline head loss, Manhole, Roughness coefficient, Manning, Sewer networks*

1. Introduction

Head losses in sewer pipelines are consisted of two main losses [2]: 1- Pipeline head losses: The hydraulic pipeline roughness or the flow coefficient allows for head losses due to pipe material, discontinuities at the joints and slime growth on the pipe surface below the water level, and 2- Local head losses: Head losses, in addition to Pipeline head losses, occur at junctions, changes of cross-section, manholes, bends and other fittings. If direct calculations are to be made, the following equation shall be used:

$$h_L = k\frac{V^2}{2g}$$

Where
h_L is the local head loss, expressed in meters (m);
k is the head loss coefficient dimensionless (Table 1);
V is the velocity of the liquid, expressed in meters per second (m/s);
g is the gravitational constant, expressed in meters per second squared (m/s)

The local head loss coefficient can be extracted from tables and graphs in related references such as table 1 [2, 5, 8, 11].

Table -1: Local head loss coefficient based on manhole condition [2]

Plan shape of manhole	Type of manhole		
	Straight	30ºbend	60 º bend
Rectangular	0.1	0.4	0.85
Circular	0.15	0.5	0.95

In some cases that water-surface elevation at manholes is important, it is recommended to calculate head loss coefficient of K based on energy method or composite energy loss method formulation [2,5,6,7,9,13,14,15,16].

$K=K_0C_DC_dC_QC_PC_B$

Where K_0 is initial head loss coefficient based on the relative size of the structure, C_D is the correction factor for the pipe diameter, C_d is the correction factor for flow depth, C_Q is the correction factor for relative flow, C_P is the correction factor for plunging flow and C_B is correction factor for benching which all of them are calculable from equations in mentioned references. Hec22 energy method used in sewer cad software use the energy method for local head loss calculation in manholes. There is also another method of local head loss calculation used in sewer cad program called AASHTO. The AASHTO method for structure head loss is based on power-loss methodologies. This method can be summarized by the following equation [1]:

$$h_s = (h_c + h_b + h_c) * C_n * C_s$$

Where h_s is structure head loss (m), h_c is contraction loss (m), h_b is bend loss (m), he is expansion loss (m), Cn is correction factor for non-piped flow (unitless) and Cs is correction factor for shaping (unitless).

Commoner locations of special head losses are manholes, curves, changes in sewer size, and junction of two or more sewers. Some engineers include allowance for the commoner losses by the use of the coefficient n [4]. And based on this idea there are two main methods for calculating total head losses: 1- adding local losses to the pipeline losses 2- accounting for local head losses by assuming a higher value of hydraulic pipeline roughness in the calculation of pipeline head loss [2]. This research is trying to answer the question of how much increase in the pipeline roughness coefficient would be enough in regard to considering local head losses at manhole structures.

2. Materials and Methods

To investigate how much increase in pipeline roughness coefficient is equal to the summation of manhole head losses and pipeline head losses, four pilot network has been hydraulically modelled in sewer cad software. As head loss may differ depending on main and secondary network or the slope of the network, Eghbalie city (Qazvin province) main and secondary network with mild slope and Tabriz city (East Azarbaijan province) main and secondary network which are steep has been selected for hydraulic modeling. The procedure is firstly calculation of pipeline head loss coefficient (h_f) based on the equation below:

$$h_f = \frac{n^2 v^2 L}{R^{4/3}}$$

Where:
n: manning coefficient of the pipeline (considered 0.011)
v: average velocity in each pipeline (m/s)
L: pipeline length (m)
R: Hydraulic radius of flow in each pipeline (1/4*(1-sinϴ/ϴ)*D)

The summation of pipeline head loss for all pipelines has been calculate and the outcome is in table 2 to 5 for each network.
Secondly, the local head loss related to each one of the manholes has been calculated with using the local head loss equation (h_L). K (local head loss coefficient) has been calculated for each manhole by three different method of 1- using tables and graphs 2- HEC 22 energy method and 3- AASHTO method in Sewer CAD software and by multiplying that into velocity head ($V^2/2g$), the local head loss of each manhole has revealed. It is noticeable that in HEC energy method, four different benching situation of flat, half, full and depressed has been considered and also in AASHTO method the situation of none pipe flow and full pipe flow both has been considered. At the end, the sum of local head loss for each method calculated is represented in table 2 to table 4 for all four different networks. Thirdly, total head loss is the sum of pipeline head loss and local head loss for each different method. And finally by dividing the total head loss (consisting of the pipeline and manhole head loss) into the sum of $v^2L/R^{4/3}$, the square root of the result would be the equivalent manning coefficient. In compare to the first chosen manning coefficient of 0.011, the increased percentage of manning coefficient has been represented in the last row of the table 2 to table 5.

2.1 Tabriz city secondary sewer network model

Secondary network model with steep slope is consisted of 2925 meter pipeline of 200 and 315 millimeters and 100 manhole structures (Fig 1). The sum of 2925 meter pipeline head loss for the secondary network of Tabriz city with considering ϴ between each two pipeline and calculating the hydraulic radius for each one is equal to 344.88 (m) and without considering manning coefficient (n^2) in the head loss equation, the sum of $v^2L/R^{4/3}$ is equal to 2850246 ($m^{5/3}/s^2$). The summary of outputs for equivalent roughness coefficient calculation has revealed in table 2.

Table -2: Total head loss including pipeline head loss and manhole head loss of the secondary network of Tabriz city

Total pipeline head loss (m)	Total manhole head loss (m)						
	Table or graph	HEC 22 energy method				AASHTO method	
		Flat	half	full	depressed	None	Full
344.9	2.57	0.356	0.05	0.03	0.357	1.55	0.84
Total head loss	347.4	345.2	344.9	344.9	345.2	346.4	345.7
ne	0.01104	0.011006	0.0110	0.011	0.01101	0.01103	0.01101
(%)	0.37	0.052	0.008	0.004	0.052	0.225	0.122

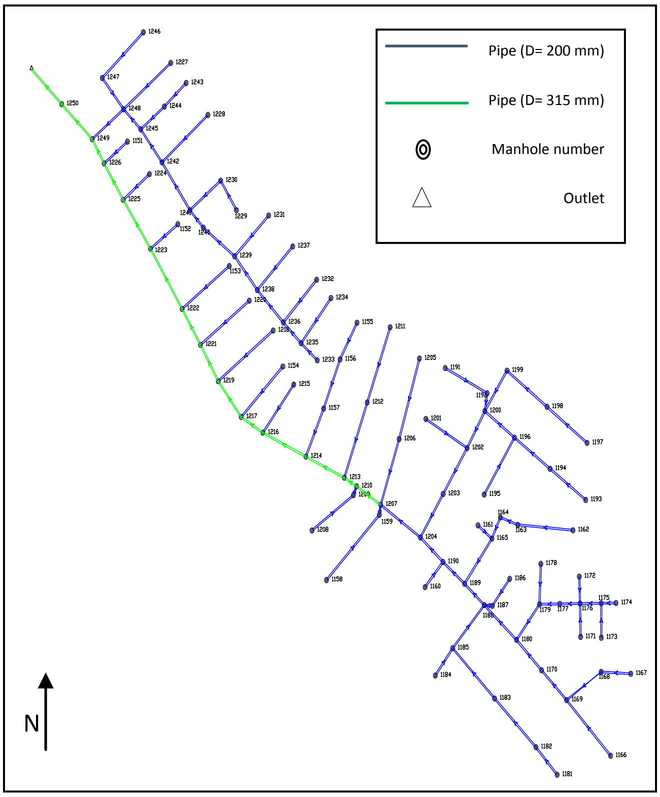

Fig-1: Tabriz city 2925 meter secondary network model

2.2 Tabriz city main sewer network model

Main network model with steep slope is consisted of 4149 meter pipeline of 200, 315, 400, 500, 600, 700 and 800 millimeters and 95 manhole structures (Fig 2). The sum of 4149 pipeline head loss for the main network of Tabriz city with considering ϴ between each two pipeline and calculating the hydraulic radius for each one is equal to 74 (m) and without considering manning coefficient (n^2) in the head loss equation, the sum of $v^2L/R^{4/3}$ is equal to 612172 ($m^{5/3}/s^2$). The summary of outputs for equivalent roughness coefficient calculation has revealed in table 3.

Table 3: Total head loss including pipeline head loss and manhole head loss of the main network of Tabriz city

Total pipeline head loss (m)	Total manhole head loss (m)					
	Table or graph	HEC 22 energy method			AASHTO method	
		half	full	depressed	None	Full
74.07	3.752	0.261	0.122	1.728	4.886	2.734
Total head loss	77.82	74.33	74.19	75.80	78.96	76.80
ne	0.01128	0.01102	0.01101	0.01113	0.01136	0.0112
(%)	2.50	0.176	0.082	1.160	3.25	1.83

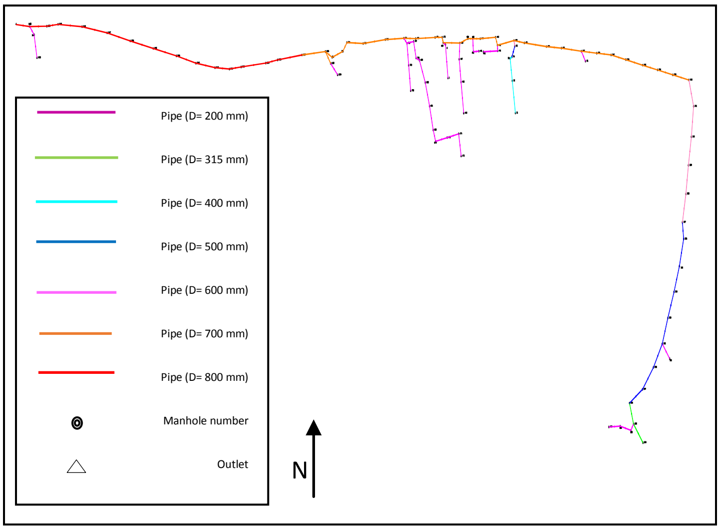

Fig-2: Tabriz city 4149 meter main network model

2.3 Eghbalieh city secondary sewer network model

Secondary network model with mild slope is consisted of 1771 meter of 200 millimeters pipeline and 64 manhole structures (Fig 3). The sum of 1771 meter pipeline head loss for the secondary network of Eghbalieh city with considering ϴ between each two pipeline and calculating the hydraulic radius for each one is equal to 9.96 (m) and without considering manning coefficient (n^2) in the head loss equation, the sum of $v^2L/R^{4/3}$ is equal to 82296 ($m^{5/3}/s^2$). The summary of outputs for equivalent roughness coefficient calculation has revealed in table 4.

Table 4: Total head loss including pipeline head loss and manhole head loss of the secondary network of Eghbalieh city

Total pipeline head loss (m)	Total manhole head loss (m)						
	Table or graph	HEC 22 energy method				AASHTO method	
		Flat	half	full	depressed	None	Full
9.96	0.58	0.059	0.009	0.003	0.0586	0.313	0.167
Total head loss	10.54	10.016	9.970	9.9611	10.016	10.271	10.124
ne	0.011315	0.01103	0.01101	0.0110	0.01103	0.01117	0.01109
(%)	2.865	0.294	0.046	0.017	0.294	1.560	0.833

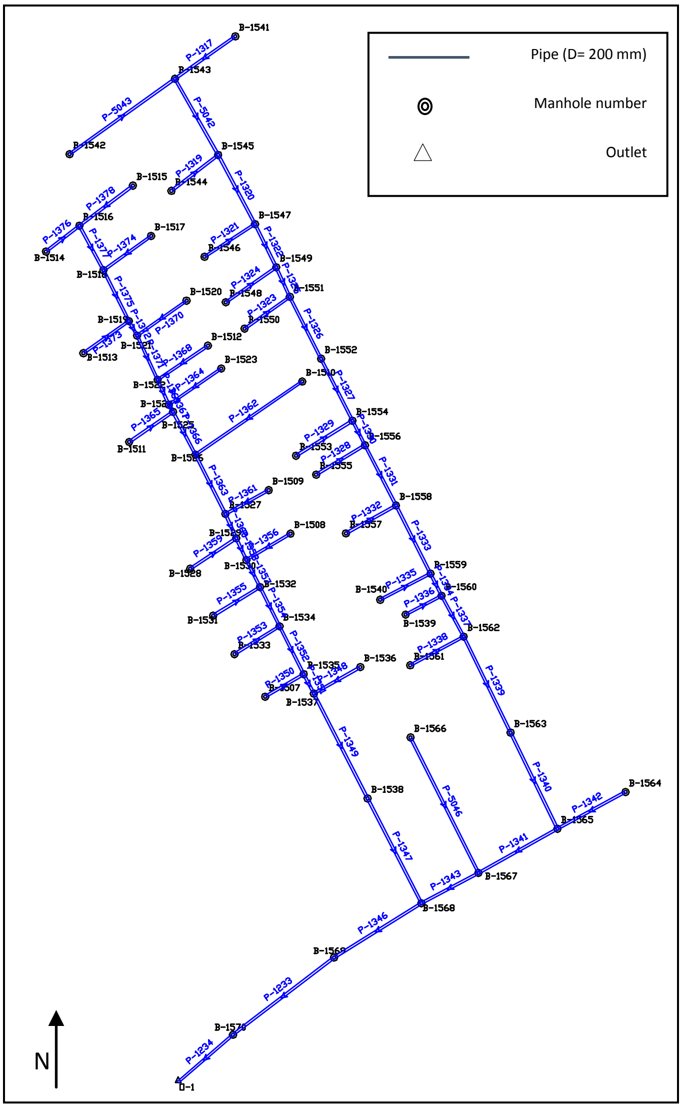

Fig-3: Eghbalieh city 1771 meter secondary network model

2.4 Eghbalieh city main sewer network model

Main network model with mild slope is consisted of 2599 meter pipeline of 200,250, 315, 400, 500 and 600 millimeters and 52 manhole structures (Fig 4). The sum of 2599 meter pipeline head loss for the main network of Eghbalieh city with considering ϴ between each two pipeline and calculating the hydraulic radius for each one is equal to 8.73 (m) and without considering manning coefficient (n^2) in the head loss equation, the sum of $v^2L/R^{4/3}$ is equal to 72187 ($m^{5/3}/s^2$). The summary of outputs for equivalent roughness coefficient calculation has revealed in table 5.

Table 5: Total head loss including pipeline head loss and manhole head loss of the main network of Eghbalieh city

Total pipeline head loss (m)	Total manhole head loss (m)						
	Table or graph	HEC 22 energy method				AASHTO method	
		Flat	half	full	depressed	None	Full
8.73	0.985	0.22	0.034	0.016	0.2254	1.169	0.73
Total head loss	9.72	8.9546	8.7689	8.7507	8.9599	9.9037	9.4645
ne	0.0116	0.01114	0.01102	0.01101	0.01114	0.01171	0.01145
(%)	5.485	1.25	0.196	0.092	1.282	6.482	4.094

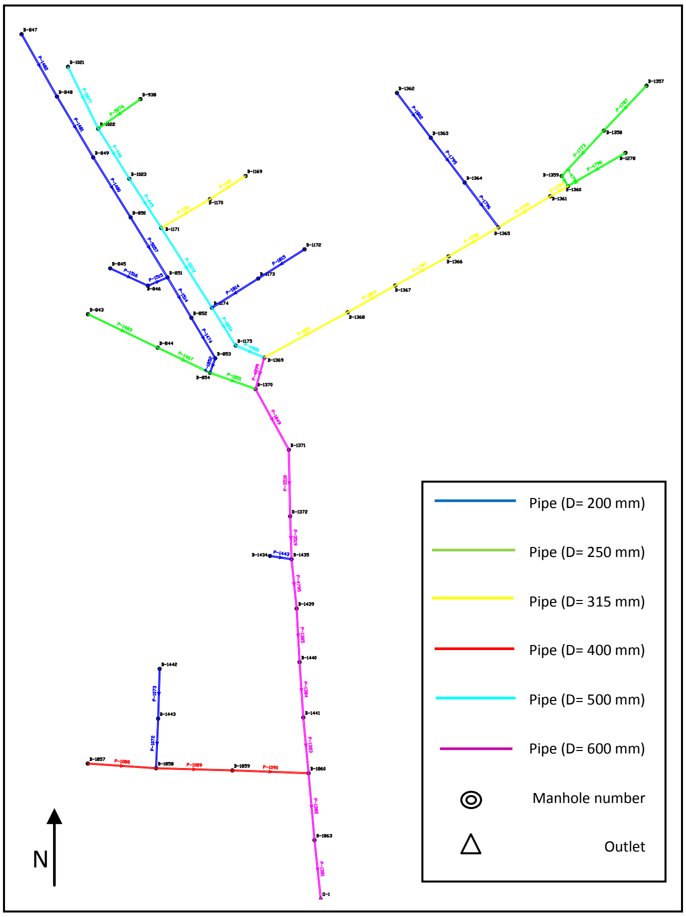

Fig4: Eghbalieh city 2599 meter main network model

3. Discussion

As the results show the increased percentage of manning coefficient regarding to manhole local head losses is different in main and secondary networks and it is also different by using different methods of calculation. Considering the wrong lower number may lead to capacity deficit and may result in pipeline clogging. So in this case the largest amount of percentage has been selected by hatching the cell in grey color. Which is less than 1 percent in secondary network of Tabriz city in compare to almost 3.5 percent of main network and almost 3 percent in secondary network of Eghbalieh city in compare to 5.5 percent of main network.

4. Conclusion

In sewer pipeline designing there are two main head losses that should be considered in energy gradient calculation: one of them is the pipe line head loss which is the result of pipeline roughness depending on its material, and the other one is local head losses which are related to local changes in sewer pipeline such as manhole structures, junctions or any other fittings. In some cases that hydraulic structure design in manholes is the main issue of the project, the local head loss at manholes should be precisely calculated while in other cases, local head losses can be considered just by increasing the pipeline roughness coefficient. Based on the outcome of this research the 2 percent is recommended for small secondary networks with little manholes while it is recommended to add 5 percent to the pipeline roughness coefficient in more complicated main networks with lots of manhole structures.

Moreover, depending on the designer's opinion, where local losses are considered negligible (e.g. networks with catchments around 300 ha), it is recommended to consider a minimum allowable drop between inlet and outlet of the manhole to avoid backwater. Drop allowance depending on velocity and flow direction changes is recommended between 3 cm for 45degree flow direction and 6 cm for 90degree flow direction [14].

REFERENCES

[1] AMEC Earth & Environmental Inc., "Modeling hydraulic and energy gradients in storm sewers: a comparison of computational methods", submitted to urban drainage and flood control district 2480W. 26th Avenue, Suite 156-B Denver Colorado 80211, October 6, 2009

[2] BRITISH STANDARD, "Drain and sewer systems outside buildings", BS EN 752

[3] City and County of Denver Department of Public Works, "Sanitary Sewer Design Technical Criteria Manual", Appendix A, Revised March 2008

[4] Davis & Sorensen," Handbook of applied Hydraulics", 1984, Third Edition, Page (40-48)

[5] Department of planning and permitting, "Rules relating to Storm Drainage Standards", City and county of Honolulu, Honolulu, Hawaii, 2000

[6] Geoffrey O'Loughlin and Bob Stack, "Algorithms for Pit Pressure Changes and Head Losses in Stormwater Drainage Systems", Australia

[7] Haestad Methods & S. Rocky Durrans, "Storm water Conveyance Modeling and Design", Bentley Institute Press

[8] Hydraulic research, "Design and Analysis of Urban Stormwater Drainage", The Wallingford procedure, Vol 1: Principles, Methods & Practice, UK National Water Council. Oxford, 1983

[9] Mackenzie L. Davis, "Water and Wastewater engineering", Design principles and practice, Michigan State University

[10] Ministry of Environment, "Design Guidelines for Sewage Works", Ontario Canada, 2008

[11] ROBERT S. HORII, City Engineer, "STORM DRAIN DESIGN", Bureau of Engineering Manual-PART G, 1986

[12] Saskatchewan Ministry of Environment," Guidelines for Sewage Works Design", 2008

[13] Texas Department of Transportation, "Hydraulic Design Manual", conduit systems energy losses Section7, 2009

[14] Thomas M. Walski et.al, "Wastewater Collection System Modeling and Design", Bentley Institute Press

[15] TxDOT, "Hydraulic Design Manual", Conduit system energy loss, 2009

[16] U.S. Department of transportation, Federal Highway administration, "Urban Drainage Design Manual No.FHWA-NHI-10-009", Hydraulic Engineering Circular No. 22, Third Edition, 2009

[17] Wayne C.Huber, "Storm water Management Model", Version 4, User Manual, Department of Civil Engineering, Oregon State University, Second Printing, 1992

BIOGRAPHIES

Sima Safarkhani was born in Tehran, Iran, in 1981. She received B.S in civil engineering from IUST university in 2004 and M.S in civil engineering from Sharif University of Technology in 2007. Her main area of research are river and hydraulic structure modelling, water resource management, LID and BMP techniques, and WSUD.

Siavash Katebizaki was born in Tehran, Iran, in 1978. He received B.S in Agricultural engineering-Irrigation from I.K.I university in 2001. His main area of research are irrigation techniques, agriculture, water engineering and drainage.