Bulletin of the *Transilvania* University of Braşov • Vol. 10 (59) Special Issue No. 1 - 2017
Series I: Engineering Sciences

ALTERNATIVE METHODS FOR DIMENSIONING GRAVITATIONAL SEWER PIPES

A. HOŢUPAN[1]

Abstract: *Traditionally, for the hydraulic calculation of gravitational sewer pipes, the Romanian technical literature is recommending the use of the Chezy formula for the flow velocity, without a clear reason or explanation for this choice.*
In this study is presented a comparison between four methods for calculating the velocity of flow, for dimensioning sewer pipes. These formulas are used by various software products in various countries, include specific roughness coefficients and therefore it is important to see the differences between them.
The comparative study presented in this paper aims to determine the calculation method which gives the greatest transport capacity, while keeping the diameter minimal.

Key words: *sewer pipes, roughness, Manning, Colebrook-White*

1.Introduction

Worldwide there are mainly four different ways of approaching the hydraulic dimensioning of sewer pipes, i.e. four different roughness coefficients for sewer pipe walls.

The comparative study was only made for vitrified clay pipes, pipes used in modern sewer systems. Table 1 presents the values for the roughness coefficients, corresponding to the four calculation methods.

Values for the roughness coefficients for vitrified clay pipes [1] Table 1

Manning Coefficient n	Hazen-Williams Coefficient c	Bazin Coefficient γ	Absolute roughness k (mm)
0.0125-0.013	110-140	0.14-0.16	0.2-0.5

From a hydraulic standpoint, the main objective is to obtain the biggest possible transport capacity, while the diameters are being kept as small as possible.

In our country, in conformity with STAS 3051-91, the minimum allowed water velocity in gravitational sewer pipes must be 0.7 m/s (the so-called self-cleansing velocity), while

[1] Technical University of Cluj-Napoca

the maximum allowed velocity is dependent on the pipe material. In the case of vitrified clay pipes, this maximum velocity must not surpass 3 m/s. [2], [7]

2. Methods

The calculation formula for uniform flow is deduced from the Chezy equation, [3]:

$$V = C \cdot \sqrt{R_h \cdot i}, \quad [m/s]; \tag{1}$$

where: V - average velocity across the pipe section, [m/s];
C - the Chezy coefficient, [$m^{0,5}$/s];
R_h - the hydraulic radius, [m];
i - hydraulic slope, [%].

The value of the flows will be determined by the equation of continuity, [3], [5], [6]:

$$Q = A \cdot V, \quad [m^3/s]; \tag{2}$$

where: - A represents the flow section, in our case a circular section:

$$A = \pi \cdot D^2/4, \; [m^2]; \tag{3}$$

and D is the internal diameter of the pipe, [m];

In this comparative study it is presumed that the fluid used is pure water, and the sewer system is running full.

Method no. 1

For determining the velocity value, the relation (1) will be used and Chezy's coefficient will be calculated with the Manning formula, [3]:

$$C = \frac{1}{n} \cdot R_h^{1/6}, \quad [m^{0,5}/s]; \tag{4}$$

where: n is Manning's roughness coefficient, n = 0.013;
R_h - the hydraulic radius; for a circular section:

$$R_h = \frac{A}{P_u} = \frac{D}{4}, \quad [m]; \tag{5}$$

where: A represents the flow section; for circular section, $A = \pi \cdot D^2/4$;
P_u is the wetted perimeter, $P_u = \pi \cdot D$, [3].

Method no. 2

The second method proposes that the velocity is determined by the use of the same relation (1), while the calculation formula for the C coefficient is the one proposed by Bazin, [3]:

$$C = \frac{87}{1 + \frac{\gamma}{\sqrt{R_h}}}, \quad [m^{0,5}/s]; \tag{6}$$

where: γ is Bazin's roughness coefficient, $\gamma = 0,14$, and R_h - hydraulic radius, relation (5).

Method no. 3

This method for determining the flow velocity is based on the Hazen-Williams equation which has the following form, [4]:

$$V = K \cdot c \cdot R_h^{0,63} \cdot i^{0,54}, \quad [m/s]; \tag{7}$$

where: K reprezents a constant, its value in S.I. is K = 0,849;
c – Hazen-William's roughness coefficient; for calculations the value is 110;
R_h - hydraulic radius, [m];
i - hydraulic slope, [%].

Method no. 4

Another method for calculating the flow velocity is the one which results from the Darcy-Weisbach relation, [1]:

$$V = \frac{1}{\sqrt{\lambda}} \cdot \sqrt{2 \cdot g \cdot D \cdot i}, \quad [m/s]; \tag{8}$$

This formula is usually used for pipes under pressure, but it may be also used for sewer pipes. Under the assumption that the flow is uniform, results the velocity for the full flow regime. For determining the Darcy friction factor, the Colebrook-White equation should be used, [3]:

$$\frac{1}{\sqrt{\lambda}} = -2\log_{10} \cdot \left(\frac{2,51 \cdot \nu}{D \cdot \sqrt{2 \cdot g \cdot D \cdot i}} + \frac{k}{3,71 \cdot D} \right) \tag{9}$$

where: λ - Darcy friction factor, dimensionless;
i - hydraulic slope, [%];
D - the internal diameter of the pipe, [m];
g - gravitational acceleration, [m/s^2];

k- absolute roughness of the pipe, k= 0,4 mm;
ν- kinematic viscosity of the fluid, ν= 1.31 $\cdot 10^{-6}$ m^2/s.

The values of the discharge will be determined (for all the four methods) based on the continuity equation. The results obtained by the use of the methods above are systematized in Tables 2-5.

The values of the discharge (l/s) and velocity (m/s), calculated by using Chezy and Manning relations (method 1) [1] Table 2

i [‰]	5		10		20		30		40		50	
D [mm]	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q
200	0.7	23.1	1.0	32.7	1.4	46.3	1.8	56.7	2.1	65.5	2.3	73.3
250	0.8	42.0	1.2	59.4	1.7	84.0	2.1	102.9	2.4	118.8	2.7	132.9
300	0.9	68.3	1.3	96.6	1.9	136.7	2.3	167.4	2.7	193.3	3.0	216.1
350	1.0	103.0	1.5	145.7	2.1	206.1	2.6	252.5	3.0	291.5	3.4	326.0
400	1.1	147.1	1.6	208.1	2.3	294.3	2.8	360.5	3.3	416.3	3.7	465.4
500	1.3	266.8	1.9	377.4	2.7	533.7	3.3	653.6	3.8	754.8	4.3	843.9
600	1.5	433.9	2.1	613.7	3.0	867.9	3.7	1062.9	4.3	1227.4	4.8	1372.2
700	1.7	654.5	2.4	925.7	3.4	1309.1	4.1	1603.4	4.8	1851.4	5.3	2069.9
800	1.8	934.5	2.6	1321.6	3.7	1869.1	4.5	2289.2	5.2	2643.3	5.8	2955.3

The values of the discharge (l/s) and velocity (m/s), calculated by using Chezy and Bazin relations (method 2) [1] Table 3

i [‰]	5		10		20		30		40		50	
D [mm]	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q
200	0.8	26.5	1.2	37.5	1.6	53.1	2.0	65.0	2.3	75.1	2.6	84.0
250	0.9	48.3	1.3	68.4	1.9	96.7	2.4	118.4	2.7	136.8	3.1	152.9
300	1.1	78.7	1.5	111.3	2.2	157.5	2.7	192.9	3.1	222.7	3.5	249.0
350	1.2	118.7	1.7	167.9	2.4	237.5	3.0	290.9	3.4	335.9	3.9	375.6
400	1.3	169.3	1.9	239.5	2.7	338.7	3.3	414.8	3.8	479.0	4.2	535.5
500	1.5	305.7	2.2	432.4	3.1	611.5	3.8	748.9	4.4	864.8	4.9	966.9
600	1.7	494.5	2.4	699.4	3.5	989.1	4.2	1211.4	4.9	1398.8	5.5	1563.9
700	1.9	741.6	2.7	1048.9	3.8	1483.3	4.7	1816.7	5.4	2097.7	6.1	2345.4
800	2.1	1052.6	2.9	1488.6	4.1	2105.3	5.1	2578.4	5.9	2977.3	6.6	3328.8

3.Conclusions

From the analysis of the values from the tables, it results that the lowest value of the discharge (for the same hydraulic slope and the same diameter) is obtained by the use of the Chezy relation for velocity calculations, when the Chezy coefficient was determined by Manning's relation (method 1). In contrast, the biggest discharge values are obtained by using the velocity calculations provided by method 4 (Darcy-Weisbach combined with Colebrook-White).

The values of the discharge (l/s) and velocity (m/s), calculated by using Hazen-Williams relation (method 3) [1] Table 4

i [‰]	5		10		20		30		40		50	
D [mm]	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q
200	0.8	25.4	1.1	36.9	1.7	53.7	2.1	66.8	2.5	78.1	2.8	88.1
250	0.9	45.7	1.3	66.4	1.9	96.6	2.4	120.2	2.8	140.4	3.2	158.4
300	1.0	73.8	1.5	107.3	2.2	156.0	2.7	194.2	3.2	226.9	3.6	255.9
350	1.1	110.7	1.6	160.9	2.4	234.0	3.0	291.3	3.5	340.3	4	383.9
400	1.2	157.3	1.8	228.7	2.6	332.5	3.3	413.9	3.8	483.5	4.3	545.4
500	1.4	282.8	2.1	411.3	3.0	598.0	3.8	744.4	4.4	869.5	5.0	980.8
600	1.6	456.9	2.3	664.3	3.4	965.9	4.2	1202.4	4.9	1404.5	4.6	1584.3
700	1.7	685.3	2.6	996.5	3.7	1448.9	4.7	1803.5	5.4	2106.6	6.1	2376.4
800	1.9	973.7	2.8	1415.8	4.1	2058.5	5.1	2562.3	5.9	2993.0	6.7	3376.3

The values of the discharge (l/s) and velocity (m/s), calculated by using Darcy – Weisbach relation (method 4) [1] Table 5

i [‰]	5		10		20		30		40		50	
D [mm]	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q
200	0.9	28.0	1.2	39.8	1.8	56.7	2.2	69.6	2.5	80.5	2.8	90.1
250	1.0	50.5	1.4	71.9	2.0	102.1	2.5	125.4	2.9	145.0	3.3	162.2
300	1.1	81.7	1.6	116.3	2.3	165.2	2.8	202.7	3.3	234.3	3.7	262.2
350	1.2	122.7	1.8	174.5	2.5	247.8	3.1	304.0	3.6	351.4	4.1	393.2
400	1.4	174.5	1.9	248.0	2.8	352.0	3.4	431.8	3.9	499.1	4.4	558.4
500	1.6	313.8	2.2	445.75	3.2	632.3	3.9	775.6	4.5	896.3	5.1	1002.7
600	1.8	506.5	2.5	719.1	3.6	1019.9	4.4	1250.7	5.1	1445.3	5.7	1616.7
700	1.9	758.9	2.8	1077.1	3.9	1527.2	4.8	1872.6	5.6	2163.8	6.3	2420.4
800	2.1	1076.8	3.0	1527.9	4.3	2165.9	5.3	2655.6	6.1	3068.4	6.8	3432.1

By using the relations of Bazin and Hazen-Williams we obtain intermediary values between the values obtained by using method 1 and method 4, but there can't be made a clear ranking because in Bazin's relation for small diameters, the discharges that result are smaller than the discharges obtained by the Hazen-Williams relation, while with the increase of the diameter and slope, the ranking changes.

Based on the obtained results, one can see that method 4 is the most optimistic, providing a greater transport capacity for the same flow section and the same slope. However, it seems that in practice, for a more conservative / secure design, method 1 is recommended.

Some scientists pretend that relation 1 can be used for all the four methods, and C will have a different expression everytime.

We will compare C's expression obtained by using method 1 and method 4, because those methods offered us minimum and maximum values of the discharge in the hypothesis where the other parameters remain constant.

Equalizing relation 1 with relation 8 gives:

$$C = \frac{1}{n} \cdot R_h^{1/6} = \sqrt{\frac{8 \cdot g}{\lambda}}, \quad [m^{0,5}/s] \tag{10}$$

From a mathematic standpoint the obtained relation is correct, although numerically the equality is not satisfied for our vitrified clay pipe scenario. This can be observed in Table 6. The differences that appear are not negligible, therefore a thorough analysis of those relations will be the subject of a further paper.

The values of the C coefficient Table 6

C	$\frac{1}{n} \cdot R_h^{1/6}$	$\sqrt{\frac{8 \cdot g}{\lambda}}$	$\frac{1}{n} \cdot R_h^{1/6}$	$\sqrt{\frac{8 \cdot g}{\lambda}}$	$\frac{1}{n} \cdot R_h^{1/6}$	$\sqrt{\frac{8 \cdot g}{\lambda}}$
D [mm]	i=5 [‰]		i=25 [‰]		i=50 [‰]	
200	46.68	56.39	46.68	57.19	46.68	57.40
250	48.45	58.26	48.45	58.98	48.45	59.17
300	49.95	59.77	49.95	60.44	49.95	60.61
350	51.25	61.04	51.25	61.67	51.25	61.82
400	52.40	62.14	52.40	62.73	52.40	62.88
500	54.39	63.97	54.39	64.50	54.39	64.63
600	56.07	65.45	56.07	65.94	56.07	66.06
700	57.53	66.70	57.53	67.16	57.53	67.27
800	58.82	67.78	58.82	68.21	58.82	68.31

References

1 *** *Quida per la progettazione e la realizzazione di fognature in gres ceramico* (*Guide Linee for the design and construction of sewerage systems using vitrified clay pipes*) http://www.tecnicoedilizia.it/uploads/cataloghi/Societa%20del%20Gres%20linee%20guida.pdf. Accessed: 29-09-2017.

2 *** NP 133-2013: *Normativ privind proiectarea, execuţia şi exploatarea sistemelor de alimentare cu apă şi canalizare a localităţilor* (*Norms regarding the design, execution and functioning of municipal water and sewerage systems*), vol. 2. Bucureşti. Ed. MATRIX ROM, 2013.

3 Marian L., Muste M.: *Hidraulică şi maşini hidraulice, volumul I*, (*Hydraulics and Hydraulic Machines, volume I*). Cluj-Napoca. Ed. Lito Institutul Politehnic, 1993.

4 https://www.aspe.org/sites/default/files/webfm/pdfs/TableBookErrata.pdf. Accessed: 29-09-2017.

5 Ianculescu O., Ionescu Gh.-C., Racoviţeanu R.: *Canalizări* (*Sewerage Systems*). Bucureşti. Ed. MATRIX ROM, 2001.

6 Ionescu Gh.-C.: *Sisteme de canalizare* (*Sewerage Systems*), Ed. MATRIX ROM Bucureşti, 2010.

7 *** STAS 3051-91: *Sisteme de canalizare - Prescripţii fundamentale de proiectare*, (*Sewerage Systems - Basic design rules*).