Analysis, Modelling and Planning the Communal Sewarage Systems

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Abstract:
The hydraulic calculations of sewage networks are done ususally by the use of nomograms being the diagrams that show the relation between the main network parameters like pipe diameters, flow rates, hydraulic slopes and flow velocities. In traditional planning of sewage networks the appropriate hydraulic values are read mechanically from the the nomograms. Another way of calculation is the use of professional programs like the SWMM5 hydraulic model and genetic or heuristic optimization algorithms. In the paper still another way of realizing the hydraulic and planning calculations is presented in which the basic hydraulic rules and formulas describing the sewage networks and their functioning are used. The numerical solutions of nonlinear equations resulted from the formulas and describing the main phenomena of sewage flows are used in the paper to solve the tasks of hydraulic calculation and planing of the networks.

Keywords: *drink water networks, hydraulic water nets modeling, water net revitalization, water net reliability*

1. Introduction

Modelling and planning of municipal sewage networks is a complex task because of the complexity of the equations describing the sewage flows in the canals. The basic hydraulic parameters describing a sewage net are sewage flows and sewage filling heights in the canals that result from the canal diameters and canal slopes. The standard approach of planning the sewage nets consists in using the nomograms which are the diagrams showing the relations between canal diameters, sewage flows, canal hydraulic slopes and flow velocities. The values of these variables are picked off from the diagrams that are results of the former calculation of the standard hydraulic formulas for computing the sewage network canals. A more advanced approach of planning the sewage networks bases on the use of professional programs for calculating the network hydraulic models like SWMM5 developed by EPA (*US Environmental Protection Agency*). The first approach with the diagrams is simple but pure mechanical and the second one is very complicated.

In the paper an indirect approach to calculate the hydraulic parameters of sewage networks is presented and it consists in relative simple numerical solutions of the nonlinear equations resulted from the basic hydraulic rules and formulas. The method proposed for modelling and planing the sewage networks enables to analyse quickly the network parameters what makes it similar to the nomograms approach and it enables to understand easily the mutual relations between the different hydraulic parameters of the network canals.

2. The Basic Assumptions

In the paper some analytical and design methods for municipal wastewater networks are presented. The networks concerned are gravitational and presented in form of graphs divided by nodes into branches and sectors. The main hydraulic parameters are sewage flows and filling heights in the canals and the factors deciding about their values are canal diameters, slopes and profiles. The nodes are the points of connection of several network segments or branches or they are the points of changing the network parameters or the points of localization of sewage inflows into the network (sink basins, rain inlets, connecting basins). There is stated that the hydraulic parameters of net canals such as the shape, dimension, slope and the roughness are constant for the segments investigated. The sewage inflow into the net nodes occurs pointwise. There is assumed that all relations concerning the sewage flows in the canals are of steady state type. In the net nodes the flow balance equations and the condition of levels consistence are satisfied.

3. The Analysis of the Sewage Net Hydraulic Parameters

The analysis of hydraulic parameters of a sewage network consists in calculating the canal filling degrees and flow velocities depending on sewage flow rates for the known cross-sections and canal slopes. The calculation is done for individual net segments using the flow values in the net nodes determined before. The method consists in numerical solving of some nonlinear equations resulted from the relations which are algebraic and describe the investigated sewage net. These relations are formulated basing on the main basic hydraulic principles and formulas [3, 4].

The equations describing the canal filling degree H/d depending on the flow rate Q have the following form [1, 3]:

– for the i-th net segment (resulted from the flow balance equation):

$$Q = q_i + \sum_{j<i} Q_j \tag{1}$$

– for $x = H/d \le 0,5$:

$$\beta \cdot F_1(x) - Q = 0 \tag{2a}$$

$$F_1(x) = \frac{\left(\varphi_1(x) - \sin\left(\varphi_1(x)\right)\right)^{\frac{5}{3}}}{\varphi_1(x)^{\frac{2}{3}}} \tag{2b}$$

$$\varphi_1(x) = 2 \cdot \arccos\left(1 - 2 \cdot x\right) \tag{2c}$$

– for $x = H/d > 0,5$:

$$\beta \cdot F_2(x) - Q = 0 \tag{3a}$$

$$F_2(x) = 2 \cdot \frac{\left(\pi - 0,5 \cdot \varphi_2(x) + 0,5 \cdot \sin\left(\varphi_2(x)\right)\right)^{\frac{5}{3}}}{\left(\pi - 0,5 \cdot \varphi_2(x)\right)^{\frac{2}{3}}} \tag{3b}$$

$$\varphi_2(x) = 2 \cdot \arccos\left(2 \cdot x - 1\right) \tag{3c}$$

$$\beta = 0,5 \cdot \tfrac{1}{n} \cdot (d)^{\frac{8}{3}} \cdot \left(\frac{1}{4}\right)^{\frac{5}{3}} \cdot J^{\frac{1}{2}} \tag{4}$$

where: d – circle diameter in [m], n – roughness coefficient in [$s/m^{1/3}$], J – canal bottom slope in %, φ – central angle, H – fulfillment height in [m], H/d – fulfillment degree, Q – flow rate in [m^3/s] for a segment, q_i – sewage inflow rate for the i-th segment.

The β parameter described by (4) depends on the canal diameter d and on the canal slope J. For the fixed values of diameters d and slopes J the parameter β will be constant. Equations (2a–3a) are nonlinear and some known approximating methods can be used to solve them. Equations (1, 2a–2c, 3a–3c) determine the model describing the main relations in the sewage net. They describe the relation between the canal fulfillment degree x and the sewage flow rate Q for the known cross-sections and canal slopes. In this model the canal fulfillment degree x means the variable that depends on the sewage inflow rates supplying the individual net nodes. The canal diameters d and bottom slopes J are the stated network parameters. Taking them into account the equation βF(x)–Q=0 can be solved in dependence on the flow rate Q. Each change of the flow rate Q causes then a change in the solution of the equation.

For the calculated canal feeling degree H/d the velocities of the sewage flow can be computed according to the following relations:

– for $H/d \le 0,5$:

$$v = \beta_1 \cdot \left(1 - \frac{\sin\varphi}{\varphi}\right)^{\frac{2}{3}} \tag{5a}$$

$$\varphi(x) = 2 \cdot \arccos\left(1 - 2 \cdot \frac{H}{d}\right) \tag{5b}$$

– for $H/d > 0,5$:

$$v = \beta_1 \cdot \left(\frac{\pi - 0,5 \cdot \varphi + 0,5 \cdot \sin(\varphi)}{\pi - 0,5 \cdot \varphi}\right)^{\frac{2}{3}} \tag{6a}$$

$$\varphi(x) = 2 \cdot \arccos\left(2 \cdot \frac{H}{d} - 1\right) \tag{6b}$$

$$\beta_1 = \frac{1}{n} \cdot (d)^{\frac{2}{3}} \cdot \left(\frac{1}{4}\right)^{\frac{2}{3}} \cdot J^{\frac{1}{2}} \tag{7}$$

Knowing the sewage net geometry (the shape, the diameters and canal bottom slopes) and the values of inflows Q one can calculate the fulfillment heights and flow velocities for the each net segment. The calculation is to do in turn for the each net segment beginning from the farthest one and finishing it for the segment that is closest to the sewage treatment plant. The method used in the following algorithm enables the fast analysis of the main net parameters (the fulfillment degrees and velocities) and gives the possibility to simulate the process of sewage flows in the network. Changing the sewage inflow values in some indicated net nodes one can calculate in the very simply way the new values of the fulfillment degrees and flow velocities in the net segments connected directly with the these nodes.

The method of calculating the new diameters d and bottom slopes J for the net canals investigated is included into the algorithm shown in Fig. 1.

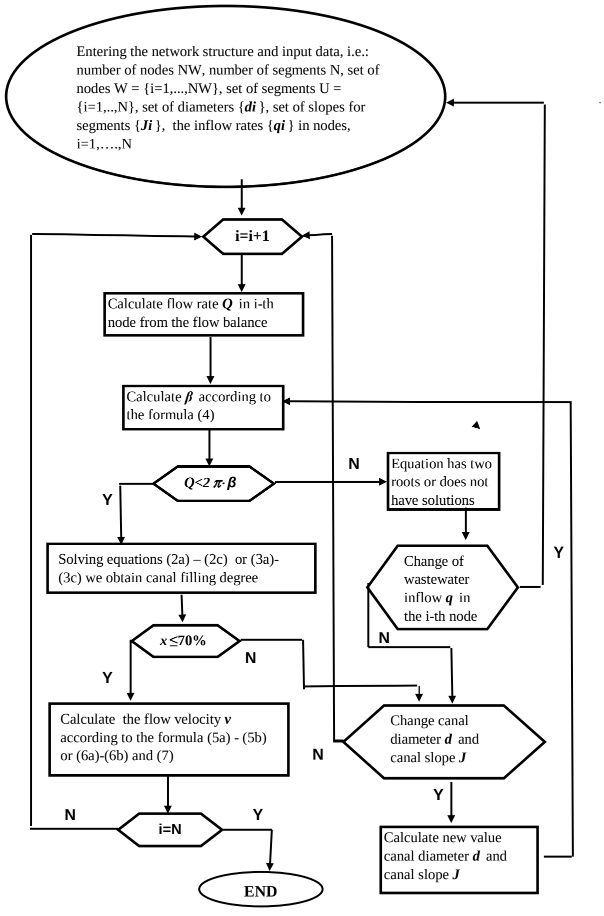

Figure 1. The algorithm of analysis of hydraulic parameters of sewage networks

4. The Features of the Bottom Canals Slopes

In the following discussion concerning the problem of planning the sewage networks two kinds of the canal slopes are relevant: the permissible slope and self-cleaning slope.

3.1 Permissible Slope

Liquid flows in canals can be in general of quiet, critical or of turbulent character. This depends on the value of the following Froude number [1, 5, 10]:

$$F_r = \frac{v}{\sqrt{g\frac{A}{B}}} \tag{8}$$

with: F_r – Froude number, v – average flow velocity [m/s], A – surface area of the active cross-section [m²], B –width of the sewage surface [m], g – gravity acceleration [m/s²].

Depending on the Froude number the sewage flow can be quiet (laminar) (for F_r<1) or critical (for F_r=1) or turbulent (for F_r>1). In the steady state flows with the free sewage level the slope of the canal bottom decides about the average flow velocity. Assuming the equality between the hydraulic slope and canal bottom the critical slope has got the following form [8]:

$$J_{kr} = \frac{g \cdot U \cdot n^2}{\alpha \cdot B \cdot R^{\frac{1}{3}}} \tag{9}$$

with: J_{kr} – critical slope [%], U – length of the canal circumference, R – canal hydraulic radius, α – Coriolis coefficient, n – roughness.

The critical slope of a canal is a function of the canal geometrical dimension and the canal filling. If the canal filling and circumference length are rising monotonically then the surface width of sewage level and the hydraulic radius are going from zero to their extremes. For a canal with the circle cross-section the surface width is growing from zero to its maximum when the canal filling is raising to the half of its diameter and afterwards it is going back to zero. The hydraulic radius is rising then from zero to its maximum reached by the canal filling equal to 81.3% and then it diminishes to the value that is reached by the canal filling equal to the half or full canal diameter. One can deduce then that the critical canal slope has got an extremum depending on the fulfillment degree x=H/d and it is as follows:

– for $x \le 0.5$:

$$J_{kr} = \frac{0{,}794 \cdot g \cdot n^2 \cdot \varphi}{\alpha \cdot \sin(0{,}5\varphi) \cdot \left(\frac{\varphi - \sin(\varphi)}{\varphi}\right)^{\frac{1}{3}} \cdot d^{\frac{1}{3}}} \tag{10a}$$

$$\varphi = 2 \cdot \arccos(1 - 2 \cdot x) \tag{10b}$$

– for $x > 0.5$:

$$J_{kr} = \frac{1{,}587 \cdot g \cdot n^2 \cdot (\pi - 0{,}5 \cdot \varphi)^{\frac{4}{3}}}{\alpha \cdot \sin(0{,}5\varphi) \cdot (\pi - 0{,}5 \cdot \varphi + 0{,}5 \cdot \sin(\varphi))^{\frac{1}{3}} \cdot d^{\frac{1}{3}}} \tag{11a}$$

$$\varphi = 2 \cdot \arccos(2 \cdot x - 1) \tag{11b}$$

with: H – height of the canal filling, d – canal diameter, φ – central angle.

The diagrams showing the changes of the canal critical slope for different canal diameters depending on the canal fulfillment degree are given in Fig. 2. The critical slope values for the canal fillings equal to 0 or 100% are going to infinity. The critical slope J_{kr} reaches its minimal value for the canal filling equal to 29.7% and then it is called as permissible slope J_g.

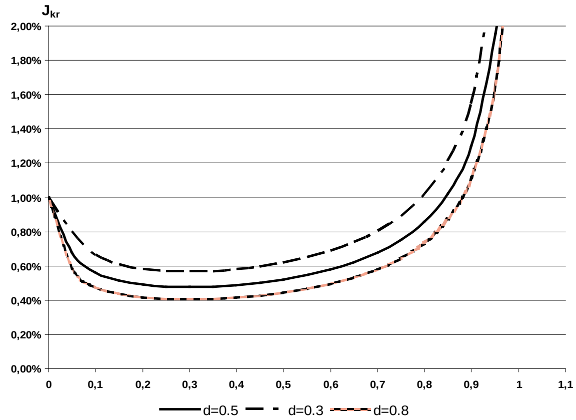

Figure 2. Relations between the critical slope J_{kr} and the filling degree x for different diameters d

Stating for a canal n=0.013, α=1 and the fulfillment degree x=29.7% the following relation for the permissible slope results:

$$J_g = \frac{3{,}778 \cdot 10^{-3}}{d^{1/3}} \tag{12}$$

It means that for securing the laminar sewage flow in a canal the canal slope value has to be less than the permissible slope. There is to see from relation (12) that the permissible slope depends only on the canal diameter d.

3.2 Canal Slope Securing the Process of the Canal Self Cleaning

The sewage passing the canals should have an appropriate large flow velocity called the self-cleaning speed. Such velocity in case of intensive sewage flows assures a dilution and a transport of the sediments that have been settled on the canal bottom at the time of smaller intensity of sewage flows. The self-cleaning speed can be secured when the friction between the sewage and canal wall is bigger than $\tau_{min} = 0.150$ [kg/m²] for the rain wastewater and bigger than $\tau_{min} = 0.225$ [kg/m²] for the communal and industrial sewage [16].

The average pass tension between the canal wall and sewage is described with the formula [16, 10]:

$$\tau = \rho \cdot \mathrm{R} \cdot \mathrm{J} \tag{13}$$

with: τ – pass tension [kg/m²], ρ – specific gravity of sewage [kg/m³], R – hydraulic radius for the canal filled partially [m], J – canal slope [%].

By means of relation (13) the minimal canal slopes J_s securing the self-cleaning speed by the gravitational sewage flow can be calculated:

– for x≤0.5:

$$\mathrm{J_s} == \frac{4 \cdot \tau_{\min} \cdot \varphi}{\rho \cdot (\varphi - \sin\varphi)} \cdot \frac{1}{\mathrm{d}} \tag{14a}$$

– for x>0.5:

$$\mathrm{J_s} = \frac{4 \cdot \tau_{\min} \cdot (\pi - 0{,}5 \cdot \varphi)}{\rho \cdot (\pi - 0{,}5 \cdot \varphi + 0{,}5 \cdot \sin\varphi)} \cdot \frac{1}{\mathrm{d}} \tag{14b}$$

with: x = H/d canal filling degree, φ – middle angle calculated from (10b) or (11b).

The diagrams showing the change of minimal canal slope in dependence on canal filling degree for different canal diameters are shown in Fig. 3.

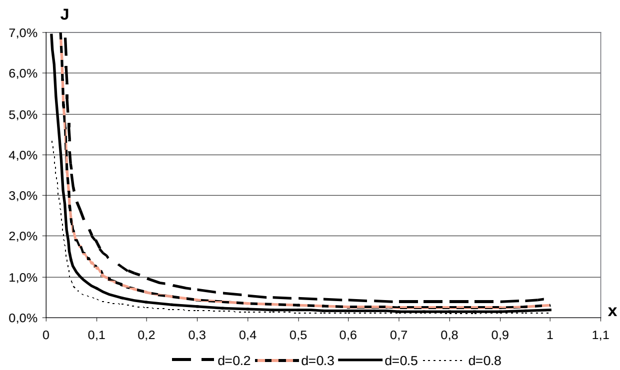

Figure 3. Relations between the minimal canal slope J and the canal filling degree x for different canal diameters d

From the diagrams results that the minimal slopes J shrink with the growing filling degrees; this behaviour is fastest for the filling degree smaller than 10%, the minimal slopes reach their minimum by the filling degree equal to 60% and then they are growing insignificantly. Inserting into the above formulas the value of hydraulic radius corresponding to the canal filling degree equal to $x = 60\%$ one can get the following formula for the minimal slope assuring the self-cleaning process in a canal:

$$\mathrm{J_s} = \frac{\tau_{\min}}{0{,}2776 \cdot \rho \cdot \mathrm{d}} \tag{15}$$

The diagrams describing the dependence between the canal minimal slope J_s and canal diameter d for different pass tensions τ_{min} are shown in Fig. 4; the slope values are diminishing with the growing diameter values d.

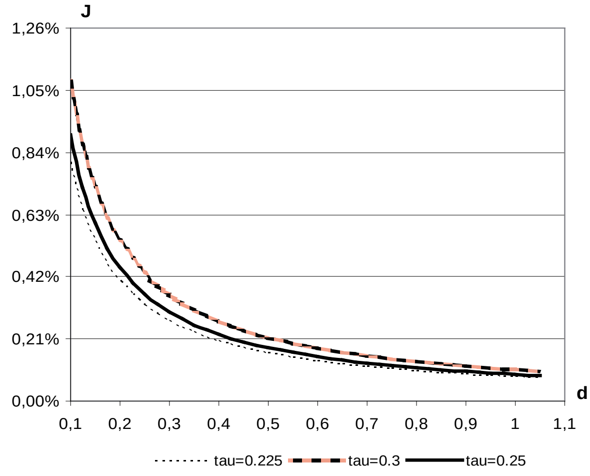

Figure 4. Relations between the canal minimal slope Js and the canal diameters d for different pass tension τ (tau)

As results from the above analysis the self-cleaning process of the canals is secured when the canal slopes are bigger than the minimal slope J_s. In Fig. 5 the diagrams describing the relations between the permisible slope J_g and the minimal slope J_s and the canal diameters d are shown.

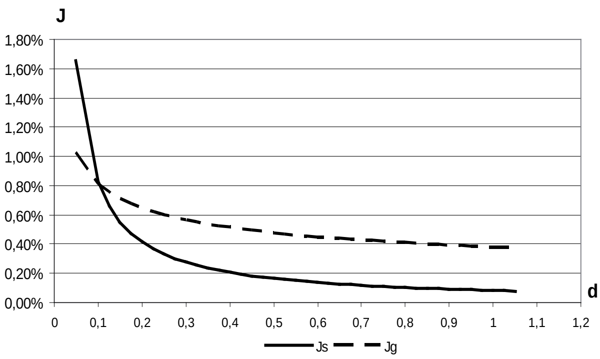

Figure 5. Relations between the minimal Js and the permisible slope Jg depending on the canal diameters d

From the diagram results that in order to assure the self-cleaning process in the canals and in the same time to secure the laminar sewage flow, the canal slope values shall be appointed between the minimal slope J_s and the permisible one J_g.

5. The Problems of the Sewage Net Planning

The following designing of the sewage net segments concerns the cases when new segments are connected to the existing sewage net or when the fillings for some segments exceed the permissible values. There is stated that the structure of the new segment and the input flows to the new designed nodes are known. The bottom slopes J and diameters d of the new canals must guarantee the laminar and self-cleaning sewage flow in them what means that some functional restrictions for the network have to be fulfilled. The sewage filling levels in the canals cannot exceed some determined values.

5.1. Limitations

The first group of limitations has to assure that the process of self-cleaning and of laminar sewage flow occur in the canals. These demands are fulfilled with the determination of specified canal slope that shall be bigger than minimal slope J_s and less than the permissible slope J_g. Assuming in (12) and (15) the parameter values n=0.013 [$s/m^{1/3}$], g=9.8067 [m/s^2], ρ=999.6 [kg/m^3] and τ_{min}=0,25 [kg/m^2] these conditions can be written down in form of the following inequalities:

$$J - J_s \qquad J - \frac{0{,}9 \cdot 10^{-3}}{d} > 0 \tag{16a}$$

$$J - J_g \qquad J - \frac{3{,}778 \cdot 10^{-3}}{d^{\frac{1}{3}}} < 0 \tag{16b}$$

The diagrams of these relations are shown in Figures 6 and 7.

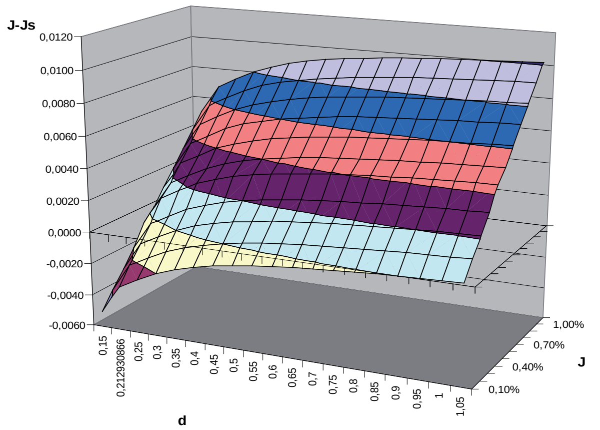

Figure 6. The diagram of the relation $J - J_s$ depending on the diameter d and on the slope J

According to relation (16a) such the values of diameters d and slopes J are to select for which the surface presented in the Fig. 6 will get the positive values.

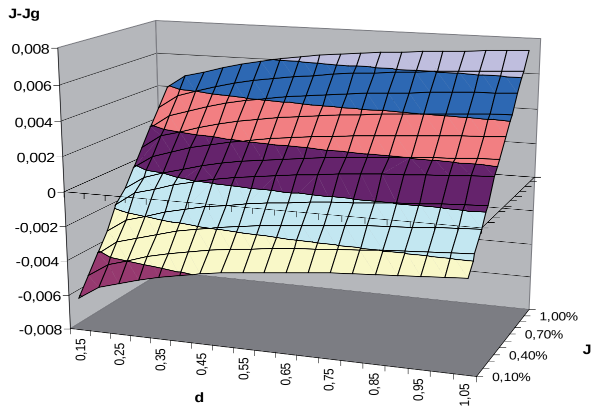

Figure 7. The diagram of relation J – Jg depending on the diameter d and on the slope J

According to relation (16b) such the values of diameters d and slopes J are to select for which the surface presented in the Fig. 7 will get the negative values.

The second group of limitations cover the existence of solutions of the nonlinear algebraic equations describing the relations between the canal filling degree x and the sewage inflow Q into the network in its steady state operation. By solving these equations the filling degree x for the known network parameters and given sewage inflows Q is stated. A detailed analysis of the equations has been done in [3] and [4]. As results from there a solution of the equations exists when the following inequalities are fulfilled:

$$2\pi \cdot \beta > Q \quad \beta = 0.5 \cdot \frac{1}{n} \cdot (d)^{\frac{8}{3}} \cdot \left(\frac{1}{4}\right)^{\frac{5}{3}} \cdot J^{\frac{1}{2}}$$

After some transformation the following relation occurs:

$$23.976 \cdot d^{\frac{8}{3}} \cdot J^{\frac{1}{2}} - Q > 0 \tag{17}$$

Regarding the necessity of securing the canals ventilation and the right operation of the inside installations of the canal system there is noted that the canal filling degree x=H/d can not be bigger than 70%. From that the following condition results:

$$\beta \cdot F_2(x=70\%) \geq Q$$

Function $F_2(\cdot)$ has the following form:

$$F_2(x) = 2 \cdot \frac{\left(\pi - 0.5 \cdot \varphi_2(x) + 0.5 \cdot \sin(\varphi_2(x))\right)^{\frac{5}{3}}}{\left(\pi - 0.5 \cdot \varphi_2(x)\right)^{\frac{2}{3}}} \tag{18}$$

with $\varphi_2(x) = 2 \cdot \arccos(2 \cdot x - 1)$.

Calculating (18) for x=70% the following conditions result:

$$5.26 \cdot \beta \geq Q \qquad 20.0735 \cdot d^{\frac{8}{3}} \cdot J^{\frac{1}{2}} \geq Q \tag{19}$$

The diagram for function $(20.0735 \cdot d^{\frac{8}{3}} \cdot J^{\frac{1}{2}} - Q)$ depending on diameter d and slope J is shown in Fig. 8. The flow value Q is equal to100 [dm^3/s].

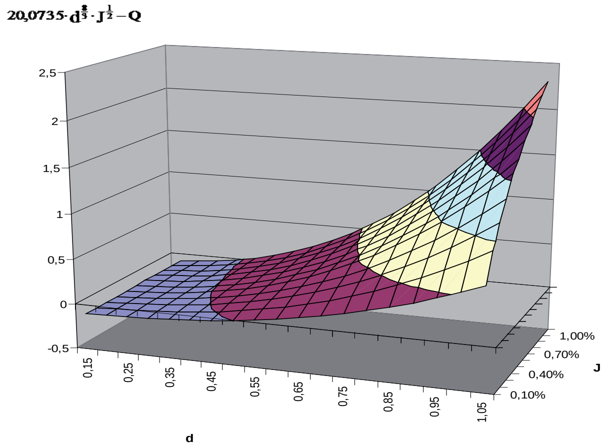

Figure 8. The diagram of function $(20.0735 \cdot d^{\frac{8}{3}} \cdot J^{\frac{1}{2}} - Q)$.

According to relation (19) such these values of diameters d and slopes J are to select for which the surface presented in Fig. 8 will get the positive values.

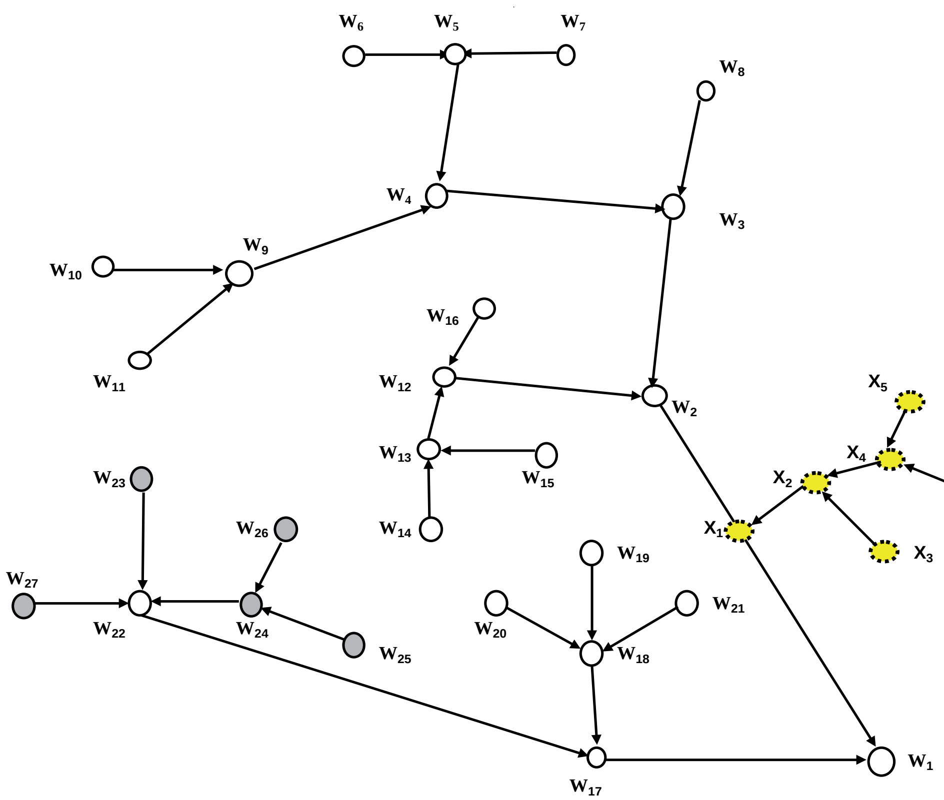

Figure 9. Diagram of the sewage network investigated

The problem presented below concerns the planning of a network branch consisting of K segments. The task is to determine such the values of diameters d and slopes J that would ensure the safe and correct sewage net operation. The net structure, segments number and length and the wall depths of the first networks segments are known. The problem consists in solving relations (16a), (16b) and (19) for each i-th segment of the designed network branch. The equations of the flows balance are fulfilled in each node of the network:

$$Q_i = \sum_{j \neq i} q_j$$

6. An Example of Modelling and Planning of a Sewage Network

The algorithm of sewage networks analysis presented above is applied in the following to investigate a sanitary sewage network consisted of 27 nodes and 26 pipes. In the network there are 15 input nodes **(W_6, W_7, W_8, W_{10}, W_{11}, W_{14}, W_{15}, W_{16}, W_{19}, W_{20}, W_{21}, W_{23} , W_{25}, W_{26}, W_{27})** and 1 output node **W_1** while the other nodes called montage nodes make only the connections of the related net pipes.

The network diagram is shown in Fig. 9 [16], [17]. The values of the sewage inflows into the network are stated in the input nodes and the sewage flows in the pipes are marked with darts on the diagram. In the montage nodes the sewage flows are to calculate according to the appropriate flow balance equations. For the individual network pipes the diameter values equal to d=0.2 m and the canal decrease values equal to J=0.5% are stated. For the network of the structure given the canal fulfillment degrees H/d and the sewage flow velocities in all pipes have been calculated by means of the formulas carried out in the earlier considerations.

The network has been calculated also using the MOSKAN program developed in IBS PAN and based on the hydraulic model SWMM5 available in Internet as an open source application [15].

With the interrupted lines the additional nodes (**X_1, X_2, X_3, X_4, X_5**) are marked which are to be added to the network existed. For the canals connecting the nodes the diameters d and decrease values J are to calculate.

The calculation results received are shown in Table 1. One can see from the table that the values calculated using the algorithm formulated in the paper are very similar to these ones received by means of the MOSKAN program. The negligible differences which are visible in the table result from the numerical roundings made in MOSKAN.

Calculation of the parameter values regarding the canal diameters d and canal decreases J have been done for two different cases.

The case no. 1 deals with the situation in which the sewage inflows in 5 network nodes W_{23}, W_{25}, W_{26}, W_{24}, W_{27} have been increased. These nodes are marked in Fig. 9 with the dark color. The inflows raising resulted with the increase of the fulfillment degrees in the canals which are connected with these nodes. The calculation results for this case are shown in Table 2. The analysis of the results shows that the canal fulfillment degree in two network pipes 21 and 26 connecting the nodes W_{22} with W_{17} and W_{17} with W_1 respectively

Table 1. Hydraulic calculation results for the sewage network shown in Fig. 9

Upper node	Lower node	Segment	input flows in node q [dm³/s]	flows in segments Q [dm³/s]	H/d [%]	v [m/s]	H/d [%] MOSKAN	v [m/s] MOSKAN
W6	W5	1	0.56	0.56	10.72	0.309	11	0.29
W7	W5	2	0.31	0.31	8.09	0.259	8	0.26
W5	W4	3	0.27	1.14	15.08	0.383	15	0.38
W10	W9	4	0.36	0.36	8.69	0.271	9	0.27
W11	W9	5	1.13	1.13	15.02	0.382	14,6	0.39
W9	W4	6	0.64	2.13	20.48	0.460	20	0.46
W4	W3	7	0.64	3.91	27.78	0.549	28	0.55
W8	W3	8	0.11	0.11	4.98	0.189	5	0.19
W3	W2	9	0.1	4.12	28.53	0.557	29	0.56
W14	W13	10	0.11	0,.11	4.98	0.189	5	0.19
W15	W13	11	0.32	0.32	8.22	0.261	8	0.26
W13	W12	12	0.23	0.66	11.59	0.325	12	0.33
W16	W12	13	0.24	0.24	7.17	0.240	7	0.24
W12	W2	14	1.86	2.76	23.29	0.497	23	0.49
W2	W1	15	0.73	7.61	39.42	0.661	39	0.66
W23	W22	16	0.56	0.56	10.72	0.309	11	0.29
W27	W22	17	0.4	0.4	9.13	0.280	9	0.27
W25	W24	18	0.81	0.81	12.79	0.346	13	0.36
W26	W24	19	0.83	0.83	12.94	0.348	13	0.38
W24	W22	20	0.09	1.73	18.48	0.433	18	0.43
W22	W17	21	1.53	4,22	28.89	0.561	29	0.56
W19	W18	22	0.83	0.83	12.94	0.348	12	0.38
W20	W18	23	0.3	0.3	7.97	0.256	7	0.26
W21	W18	24	0.19	0.19	6.42	0.223	6	0.22
W18	W17	25	0.22	1.54	17.46	0.419	18	0.49
W17	W1	26	0.57	6.33	35.70	0.629	36	0.63
W1	Sewage plant			13.94				

is too high and it exceeds the acceptable value of 70%. In this situation these pipes are to reconstruct what means that their new diameters d and decrease degrees J are to be calculated in such the way that the pipes functioning will be already correct. To do it the inequalities in the relations (16a–16b) and (19) have to be solved.

The results of the calculation are shown in Table 3. From the analysis of the table data results that the new canal diameters d and decrease degrees J are the same for the both pipes 21 and 26. For these new values of d and J the new fulfillment degreases H/d and flow velocities in the related pipes have been calculated. The present values of H/d for the both pipes exceed slightly 50%.

In the case no. 2 some new canal segments have been added to the network existed. The new nodes added (**X_1, X_2, X_3, X_4, X_5**) are noticed with the interrupted lines on Fig. 9. There is stated that the network structure, the number and the lengths of all pipes, the sewage flow values in the network nodes as well as the deepening values of the beginning pipes of the net are known. The task to be solved consists then in calculating such the diameters and decrease degreases of the new canals with which the network functioning will be correct.

The given input data concerning the network and the calculation results received are shown in Table 4. One can see from the table that the values of d and J calculated for the new segments are the same what results of the small values of the projected sewage inflows q. For such the inflows the canal fulfillment degreases do not exceed the value of 20%. For all segments added their decrease values are placed between the minimal decrease J_s and the border decrease J_g.

Table 2. Calculation results for the network pipes with the inflows changed in the nodes stated

Upper node	Lower node	Segment	input flows in node q [dm³/s]	flows in segments Q [dm³/s]	H/d [%]	v [m/s]	H/d [%] MOSKAN	v [m/s] MOSKAN
W23	W22	16	4.56	4.56	30.06	0.574	30	0.58
W27	W22	17	4.4	4.4	29.51	0.568	30	0.57
W25	W24	18	4.81	4.81	30.90	0.582	31	0.58
W26	W24	19	3.53	3.53	26.37	0.533	26	0.53
W24	W22	20	3.69	12.03	51.10	0.745	51	0.75
W22	W17	21	1.53	22.52	79.47	0.841	79	0,84
W17	W1	26	0.57	24.63	89.27	0.832	89	0.83

Table 3. Calculation results for the network pipes with the inflow values changed

Upper node	Lower node	Segment	Flows in segment Q [dm³/s]	d [m]	J [%]	H/d [%]	v [m/s]
W22	W17	21	22,52	0,25	0,5	52	0.609
W17	W1	26	24,63	0,25	0,5	55	0.635

Table 4. Calculation results for the new network branch added

Upper node	Lower node	Segment	input flows in node q [dm³/s]	flows in segments Q [dm³/s]	d [m]	J [‰]	H/d [%]	v [m/s]
X5	X4	L1	1.86	1.86	0.25	4.98	15.4	0.449
X6	X4	L2	0.56	0.56	0.25	4.96	10.6	0.357
X4	X2	L3	0.64	3.06	0.25	4.99	19,8	0,523
X3	X2	L4	0.73	0.73	0.25	4.95	13.7	0.419
X2	X1	L5	1.86	5.65	0.25	4.99	25	0.6

The new net branch planned has been added to the network existed on the pipe connecting the node $\mathbf{W_2}$ with the node $\mathbf{W_1}$ being the sewage receiver via the new node $\mathbf{X_1}$. The wastewater flows into the node $\mathbf{W_1}$ from the node $\mathbf{W_2}$ being the element of the network existed and from the node $\mathbf{X_2}$ being the element of the network new planned. There is a risk then that the sewage inflow into the node $\mathbf{X_1}$ would be so high that the fulfillment degree H/d of the canal placed under this node would exceed the value of 70%. In such the situation the net segment lying between the nodes $\mathbf{X_1}$ and $\mathbf{W_1}$ should be reconstructed. From the calculation done results however that from the node $\mathbf{W_2}$ the sewage volume of 7.61 [dm3/s] flows away while from the node $\mathbf{X_2}$ the sewage volume of 5.65 [dm3/s] runs off. From the mass balance results then that the sewage volume of 13.26 [dm3/s] flows into the node $\mathbf{X_1}$. The following calculation shows that for the canal diameter and canal decrease values equal to d=0,2 and J=0.5% the fulfillment degree H/d for the pipe connecting the nodes $\mathbf{X_1}$ and $\mathbf{W_1}$ will amount to 54.1% and the corresponding flow velocity will be equal to v=0.6 [m/s]. In this situation there is no need to reconstruct the referred segment.

7. Conclusions

In the paper a simple and practical approach for planing sewage networks is proposed that differs from the approaches commonly used in the today's practice. The standard method of sewage network calculation consists in using nomograms which enable to calculate quite mechanically the basic parameters of the designed nets such as canal diameters and slopes on the base of determined sewage inflow values. The modern planning approach consists in applying advanced computer programs like SWMM developed by EPA or MIKE URBAN developed by DHI that use in their calculation the network hydraulic models. This approach requires an advanced computer knowledge from the network planers. The important obstacle in using this software is the need of having a calibrated hydraulic model of the network under investigation. To calibrate the model a GIS system to generate the hydraulic graph of the network and a monitoring system to collect the measurements data have to be installed in the waterworks what generates expensive costs. The approach for the sewage networks planning presented in the paper is an indirect solution between the standard and modern approaches trying to keep their advantages and to eliminate their drawbacks. It uses the analytical relations concerning the hydraulics and geometry of sewage networks and it transforms them to nonlinear equations from which demanded canal fillings and sewage speeds or canal diameters and slopes can be directly calculated. The analysis of the equations formulated enables to determine available maximal sewage inflows ingoing to the network nodes. The calculation can be done quickly and exactly avoiding the use of the network hydraulic model. The computational example presented for steady state modelling and planning of sewage networks is rather simple but the algorithms proposed can be either used unproblematic for modeling and designing more complex municipal sewage systems.

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