OPTIMAL DESIGN OF WATER SUPPLY NETWORKS IN BUILDINGS

SÂRBU, Ioan

Department of Building Services,
"Politehnica" University of Timisoara, Romania

1. INTRODUCTION

The internal cold and warm water supply networks do have the role to permanently assure the discharge and necessary pressure at the consumption points, being necessary important investments in the total cost of water supply system.

At the same time, the big volume of building constructions and social-cultural edifices and the more reduced working time starting from design to execution involves the use in design of the means of bigger efficiency and precision for the calculus and dimensioning of internal water distribution networks.

Classically, the pipes diameters are chosen according to the average economical velocities, which can't consider the dynamics of the economic and energetic parameters of these networks.

In this paper an improved model is developed for optimal design of networks with inferior distribution for the water supply of buildings, implemented in a computer program for IBM-PC compatible systems. This program might be applied at each significant change interfered in the economic policy.

2. FORMULATION OF THE COMPUTATIONAL MODEL

There are considered as known following basic data: the type and number of water consumers; the scheme of columns and the distribution plan; the length, the local friction factor and the equivalent of discharge, adequate to each pipe section; the absolute roughness of pipes; the water temperature; the geodesic head in the nodes of network, measured to the consumer situated in the most unfavorable position on each column; the use pressure for each column.

After issuing the columns scheme and the distribution plan, there are numbered the pipes of network. It is established the repartition of the calculus discharge in pipes, by using the general relation (1) for civil buildings and relation (2) for social-cultural buildings [11]:

$$q_{ij} = B(AC\sqrt{E_{ij}} + 0{,}004E_{ij}) \tag{1}$$

$$q_{ij} = ABC\sqrt{E_{ij}} \tag{2}$$

in which:

q_{ij} – the calculus dicharge of pipe *ij*;

E_{ij} – the sum of discharge equivalents of consumption points supplied by pipe *ij*;

A – coefficient function to the condition of water supply in distribution network;
B – coefficient function to the water type (cold or warm);
C – coefficient function to the destination of the building.

The head loss h_{ij} for a pipe ij is given by the functional relation:

$$h_{ij} = \frac{8}{\pi^2 g} \frac{q_{ij}^2}{D_{ij}^4} \left(\lambda_{ij} \frac{L_{ij}}{D_{ij}} + \zeta_{ij} \right) = \frac{8}{\pi^2 g} \lambda_{ij} \frac{Le_{ij}}{D_{ij}^r} q_{ij}^2 \tag{3}$$

in which:
D_{ij}, L_{ij}, Le_{ij} – diameter, length and equivalent length of pipe ij;
h_{ij} – head loss in pipe ij;
λ_{ij} – friction factor Darcy-Weissbach of pipe ij;
ζ_{ij} – sum of the local friction factors of pipe ij;
g – gravitational acceleration;
r – an exponent having the value 5.0.

Considering that during the operation of the network it is consumed water pumping energy, its optimal design imposes to respect the hydraulic conditions for assuring the discharge and use pressure in all consumption points, as well as the economic-energetic conditions, by minimizing a objective function [6]:

$$F_c = \xi_1 \sum_{ij=1}^{T} \left(a + b D_{ij}^{\alpha} \right) L_{ij} + \psi G \left(\Sigma h_{ij} + H_0 \right) \to \min \tag{4}$$

where:

$$r_a = \frac{(1+\beta_o)^t - 1}{\beta_o (1+\beta_o)^t} \tag{5}$$

$$\xi_1 = r_a p_1 + \frac{t}{T_r}; \ \xi_2 = r_a p_2 + \frac{t}{T_r} \tag{6}$$

$$\psi = \frac{9{,}81}{\eta} (f \sigma \xi_2 + 8760\, r_a e \tau) \tag{7}$$

in which:
a, b, α – cost or specific energy parameters depending on pipe material;
G – pumped discharge in pipes network;
Σh_{ij} – sum of head losses on the most unfavorable pipe route;
H_0 – geodesic and use component of the pumping total dynamic head;
η – efficiency of pumping station;
f – installation cost of unit power;

σ – a factor greater than one which takes into account the installed reserve power;
e – cost of electrical energy;
$\tau = T_p/8760$ – pumping coefficient, which takes into account the effective number T_p of pumping hours per year;
p_1, p_2 – repair, maintenance and periodic testing part for network pipes and pumping station, respectively;
$\beta_o = 1/T_r$ – amortization part for the operation period T_r;
t – period for which the optimization criterion expresses by the objective function is applied, having the value 1 (minimum annual expenses or minimum energetic consumption) or T_r (total updated minimum expenses).

The general function (4) enables us to obtain a particular objective function by particularization of the time parameter t and of the other economic and energetic parameters, characteristic of the distribution system. For example, from $t = 1$, $r_a = 1$, $e = 1, f = 0$ the minimum energetic consumption criterion is obtained.

Equating with zero the partial derivative of the function (4) in relation to each diameter D of the network, it is obtained the general expression of the optimal diameter.

$$D_{ij} = (EG)^{\frac{1}{\alpha+r}} \lambda_{ij}^{\frac{1}{\alpha+r}} q_{ij}^{\frac{2}{\alpha+r}} \quad (8)$$

in which the economic-energetic factor E of the pipes is expressed by the equation:

$$E = \frac{8\psi r}{\pi^2 g \xi_1 b\alpha} \quad (9)$$

Table 1 contains the values of incorporate specific energy parameters (a, b, α) in pipes manufactured of cooper, steel, polypropylene (PP–R), netlike polyethylene (PER), chlorinated polyvinyl chloride (PVC–c) and polybutene (PB).

No.	Pipe material	Parameter			Roughness
		a	b	α	Δ [mm]
0	1	2	3	4	5
1	Cooper	0.20	7945	2.03	0.001
2	Steel	0.18	2780	1.98	0.10
3	PP-R	0.17	990	2.03	0.007
4	PER	0.15	2134	2.32	0.01
5	PVC-c	0.13	562	1.97	0.001
6	PB	0.10	908	2.20	0.007

Table 1. Incorporate specific energy parameters and roughness of the pipe wall

In the case of the transitory turbulence regime of water flow, the friction factor λ_{ij} is calculated with the folowing explicit formula [1]:

$$\sqrt{\lambda_{ij}} = \frac{A_2 + \sqrt{A_2^2 + 20{,}38 A_1 \sqrt{\lambda_p}}}{2{,}55 A_1} \tag{10}$$

where:

$$A_1 = \frac{q_{ij}\Delta}{D_{ij}^2 \nu} \quad (11) \qquad A_2 = (1{,}274 A_1 + 8)\sqrt{\lambda_p} - 4 \tag{12}$$

$$\sqrt{\lambda_p} = \frac{1}{-2\lg\dfrac{\Delta}{D_{ij}} + 1{,}138} \tag{13}$$

in which:

Δ – the absolute roughness of the pipe wall (table 1);
ν – kynematic viscosity of water, as a function of its temperature;
λ_p – friction factor for quadratic turbulence regime of water flow.

The kynematic viscosity of water is given by the relation:

$$\nu = \frac{1{,}79 \cdot 10^{-6}}{1 + 0.03370\theta + 0.000220\theta^2} \tag{14}$$

where:

θ – the water temperature.

The equation system (9) and (11) which contains the unknown λ_{ij} and D_{ij} is solved by successive approximations.

For the route where is situated the consumption point in the most unfavorable situation it is established the water load necessary H_{nec}, in order to assure the good functioning of all consumers:

$$H_{nec} = \Sigma h_{ij} + H_g + H_u \tag{15}$$

in which:

Σh_{ij} – the head loss on the most unfavorable pipes route,
H_g – geodesic head;
H_u – use pressure at the most unfavorable consumption point.

For the routes where are situated the other consumption points, it is calculated the available pressure in the limit of which there are established the diameters of the respective pipes, with the condition of not exceeding the maximum velocities allowed for water in the pipes [10], [11]. The available surplus of pressure head, calculated as difference between the head loss on the most unfavorable route and the head losses on the supply route of the adequate consumers, is taken over by the adjustment diaphragms. The diameter, in mm, of adjustment diaphragms is calculated with formula:

$$D_0 = \alpha_0 \sqrt{\frac{q}{\Delta H^{0,5}}} \quad , \tag{16}$$

where:
q – the discharge through the diaphragm, in dm^3/s;
ΔH – available surplus of pressure head, in mm H_2O;

$$\alpha_0=27{,}1-3{,}55\beta,$$

in which: β represents the ratio between thickness and diameter of the diaphragm.

2. COMPUTER PROGRAM „DIREINT”

Computer program DIREINT has been elaborated on the basis on the developed computational model. It was realized in FORTRAN programming language, for IBM-PC compatible computers. The program allows the classic or optimized design of any internal water supply network with inferior distribution, in case that the water load necessary of the supply point must be determined.

This program require a specific way to number pipe sections and nodes, namely that the final node of section to have identically its order number. One of the terminal nodes is taken as 1, aterwards at each ramification a number is given to the node and the respective upstream section, only after all the supply ways from the considered ramification have been consumed. Thus, every section has an order number and is defined by an initial and final node.

The input data files are:

Datgen.dat – general data and economic-energetic parameters;

Cartron.dat – characteristics of the pipes (initial node; final node; length, equivalent of discharge, geodesic head of initial nod, sum of local friction factors);

Matras.dat – matrix of routes containing the nodes of pipe sections plus a last fictious node “0”;

Presut.dat – use pressures on routes, in m.

Diastan.dat –list of the commercial diameters, în mm.

Vitecon.dat – matrix of economical velocities, in m/s and the adequate discharges, in dm^3/s.

Delivered results (file *direint.rez*) are following:

– equivalent of discharge, calculus discharge and diameter for each pipe;

– water velocities and head losses through pipes;
– diaphragms diameter of each route;
– necessary pressure:head in consumption points;
– water load necessary in supply point.

The computational model and the computer program were tested for more samples of numerical calculus.

3. NUMERICAL APPLICATION

It is considered the cold water supply network of a civil building with pit and two-floors, having the isometric scheme in figure 1. It is achieved of steel and the condition for the cold water supply is of 24 hours/day. Following data are known: water temperature θ = 15°C and the use pressure H_u = 2 m H_20.

Route	Pipe *i-j*	L_{ij} [m]	□	E_{ij}	q_{ij} [dm^3/s]	D_{ij} [mm]	v_{ij} [m/s]	h_{ij} [m H_2O]	H_g [m]	H_{nec} [m H_2O]	D_0 [mm]
0	1	2	3	4	5	6	7	8	9	10	11
1	2-1	4.3	22.5	0.50	0.075	15	0.4	0.32	1.3	2.0	–
	3-2	1.5	1.0	1.40	0.807	25	0.4	0.03	2.8	3.62	
	4-3	1.3	0.5	0.50	0.232	25	0.5	0.03	4.1	5.15	
	5-4	1.5	1.0	1.40	0.292	25	0.6	0.06	5.6	6.48	
	6-5	1.3	0.5	0.50	0.311	25	0.6	0.05	6.9	8.03	
	13-6	9.5	14.0	1.40	0.358	25	0.7	0.73	8.4	9.38	
	17-13	4.0	2.5	0.00	0.506	32	0.6	0.13	8.4	11.61	
	21-17	3.0	1.0	0.00	0.572	32	0.7	0.10	8.4	11.74	
	25-21	6.0	2.0	0.00	0.631	32	0.8	0.25	8.4	11.84	
	26-25	10.0	2.0	0.00	0.685	32	0.9	0.43	8.4	12.09	
2	8-7	4.3	22.5	0.50	0.075	15	0.4	0.32	1.3	2.0	–
	9-8	1.5	1.0	1.40	0.207	25	0.4	0.03	2.8	3.62	
	10-9	1.3	0.5	0.50	0.232	25	0.5	0.03	4.1	5.15	
	11-10	1.5	1.0	1.40	0.292	25	0.6	0.06	5.6	6.48	
	12-11	1.3	0.5	0.50	0.311	25	0.6	0.05	6.9	8.03	
	13-12	9.5	14.0	1.40	0.358	25	0.7	0.73	8.4	9.38	
3	15-14	2.8	17.0	1.05	0.154	15	0.9	0.94	2.8	2.0	17.0
	16-15	2.8	1.0	1.05	0.217	20	0.7	0.15	5.6	5.74	
	17-16	9.5	13.5	1.05	0.266	20	0.8	1.11	7.1	8.68	
4	19-18	2.8	17.0	1.05	0.157	15	0.9	0.94	2.8	2.0	16.2
	20-19	2.8	1.0	1.05	0.217	20	0.7	0.15	5.6	5.74	
	21-20	9.5	13.5	1.05	0.266	20	0.8	1.11	7.1	8.68	
5	23-22	2.8	20.5	1.05	0.154	15	0.9	1.07	2.8	2.0	15.4
	24-23	2.8	0.5	1.05	0.217	20	0.7	0.14	5.6	5.87	
	25-24	9.5	13.5	1.05	0.266	20	08	1.11	7.1	8.81	
Water load necessary:								H_{nec} = 12.52 m H_2O			

Table 2. Essential data and numerical results of computer program DIREINT

There is performed the optimal design of the pipes of this internal water supply network according to the computational model developed above, by considering a transitory turbulence regime of water flow and the optimization criterion used was that of minimal energetic consumption.

The basic data and numerical results obtained with program DIREINT, for following average values of the economic-energetic parameters: $\beta_0 = 0.10$, $p_1 = 0.04$, $p_2 = 0.06$, $\eta = 0.75$, $\sigma = 1.1$, $\tau = 0.35$ are presented in table 2.

The numerical results obtained by applying the classic method for the design of the considered pipes network lead to water load necessary $H_{nec} = 12.54$ m H_2O.

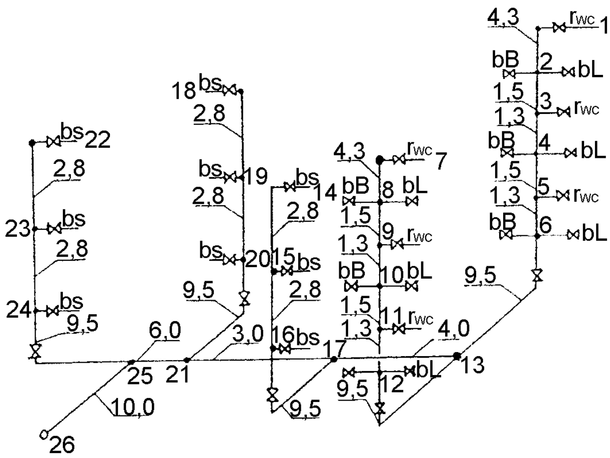

Fig. 1 Isometric Scheme of Internal Water Supply Network
bB – cock system; bL – basin; r_{wc} – water closet; bs – kitchen sink

It is concluded that the results obtained with the optimization method differ very little to those obtained by using the diagrams in literature [4], [11] and the updated values of average economical velocities [10]. This confirm the validity of the mathematical model based on which there was elaborated the computer program.

4. CONCLUSIONS

The optimal design model developed in this paper is programmable on automate microsystems and presents the advantage that it gives directly optimal commercial diameters, allowing to consider the time variation of the main economic parameters at the analysis of optimal solutions for internal water distribution networks, offering the possibility of an operative and efficacious calculus in comparing constructive alternatives.

The elaborated computer program becomes a modulus in a general program, for the computer aided design of the water supply installations in buildings and dwelling assemblies.

REFERENCES

[1] ARSENIE, D. O formulă pentru calculul coeficientului de rezistență Darcy-Weisbach de utilizat la proiectarea conductelor sub presiune, Hidrotehnica, nr. 12, 1983.

[2] CARLIER, M. Hydraulique générale et appliquée, Eyrolles, Paris, 1980.

[3] DESMADRIL, M. La programmation sous Windows, Eyrolles, Paris, 1990.
[4] DUMITRESCU, L. Instalații sanitare pentru ansambluri de clădiri, Editura Tehnică, Bucureşti, 1980.
[5] HAESTAD METHODS, Computer Applications in Hydraulic Engineering, Haestad Press, Waterbury, 1999.
[6] SÂRBU, I. Energetical optimization of water distribution systems, Editura Academiei Române, Bucureşti, 1997.
[7] SÂRBU, I. BORZA, I. Optimal design of water distribution networks, Journal of Hydraulic Research, no. 1, 1997.
[8] SÂRBU, I. KALMAR, F. Optimal design of pipe distribution networks, Prooc. of the Internat.Symposium on Environmental Hydraulics, Tempe, Arizona, 2002.
[9] SÂRBU, I. KALMAR, F. Optimization of looped water supply networks, Periodica Polytechnica Budapest, no. 46/1, 2002.
[10] Manualul inginerului de instalații, Editura Artecno, Bucureşti, 2002.
[11] Alimentări cu apă la construcții civile şi industriale, STAS 1478.

VÍZELLÁTÁSI RENDSZEREK OPTIMÁLIS TERVEZÉSE ÉPÜLETEKBEN

Ebben a cikkben bemutatásra kerül egy optimalizálási modell az alsóelosztású vízellátási rendszerekre vonatkozóan. A modell alapján meghatározhatók a gazdaságossági szempontból optimális csőátmérők. A modell alapján kidolgozásra került FORTRAN programozási nyelven egy számítógépes program. A program segítségével könnyen megvizsgálható a különböző kiépítési megoldások gazdaságossága.