COMPUTER TECHNIQUES IN THE CAPACITY DESIGN OF PIPE NETWORKS

by

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ABSTRACT:
This article summarizes a new method for the capacity design of pipe networks using digital computers.

The method is based on successive iteration technique.

The input data and output results of the computer program are simplified to enable wide uses of the program. A sub-program is attached to the main one to provide an automatic graphical output of the design, hence reducing the engineers efforts in examining and drawing the results, and at the same time minimizing human errors. This sub-program is optional.

The units used with the program can be metric or British. A parameter is introduced to take care of throughout the analysis, this choice.

INTRODUCTION:
Many engineers and researchers have been involved in the uses of computers on the analysis side of pipe networks (Ref.7-9) while less work has been done on the design side. This may be due to the fact that engineers are generally concerned with the problems of existing networks, trying to find out how the system is operating and suggest modifications for improvement.

The increase in the number of new cities required in many developing countries, made it necessary to give more thought to develop fast methods for the design of networks for water supply.

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Various methods and computer programs (Ref. 1, 2, 3, 4) have been developed for this task; however most of them are rather difficult for many designers to follow and require much time and more experience if they are to be used.

The article summarizes the development of method and computer program for directly sizing pipes in a network when demands and all heads are fixed according to the consumers requirements. The method developed involves successive analysis of the network. The analysis is based on the node balance iteration technique (Ref. 5).

The input data for the program is simplified and reduced to the minimum. Emphasis is made to develop a simplified computer output which can be easily examined and interpreted by the engineer. The computer program provides the user with a choice of tabulated results or graphical output. In the latter case a complete configuration of the network, together with the final results for the flow, pressures and pipe diameters are drawn.

Review of Previous Work

Karmeli (1) was one of the early researchers on the uses of digital computer in the design of pipe networks. He employed linear programs to design hydraulic networks. Their formulation is only valid in branch networks, i.e. for network without loops.

The treatment of networks with loops by non-linear programming was attempted by Jacoby (2). The network presented was rather simple.

Waranatada (3) suggested a program to calculate the least cost of a design network, and it was based on Jacoby's method. He concluded that this procedure would require a good deal of engineering judgement.

Most recent work done in this field is by Rasmusen (4). He presents a heuristic procedure for optimization of water supply networks. The procedure calculates a least economic cost solution.

Boundary Conditions in Pipe Network Design

Basically there are two main cases, in the terms of boundary conditions, in the design of pipe networks. In the first one the boundary conditions are fixed pressure and draw-off, or supply, at the nodes which are assigned according to the demands: the task is then to compute the size of the pipes required. In the second case the boundary conditions are fixed flow through each pipe with fixed supply, or draw-off at the nodes. the task is then to calculate the pipe sizes required irrespective of the pressure at the nodes.

This article will be concerned with the first case since in practice the engineer is generally interested in satisfying the consumers at each area to get sufficient pressure and supply.

Details of the Design Method Developed

The method developed and programmed is summarized below:

1— The pressure at the nodes are fixed by the user according to the need.
2— The design velocity of the flow "V" through all pipes is assumed between 3 to 5 fps (0.92-1.5 m/s). This could be altered if needed.
3— The theoretical diameters "D" are computed using equation (2) below which is a rearrangement of Hazen-William's formula (Ref. 5).

\[
H = \frac{4.87 L}{C^n \times D^{4.87}} \times Q^n \quad \text{.............(1)}
\]
Since $Q = \frac{\pi}{4} D^2$ (for circular section).

$$D = \frac{4.87 \cdot L \left( \frac{V \cdot \pi}{C \cdot 4} \right)^n}{H} \left( \frac{1}{4.87 - 2n} \right)$$

Where $L$ = length of the pipe in feet, $H$ = head loss in feet.
$Q$ = discharge in cfs. $C$ = Hazen Williams coefficient.
$n$ = constant depends on Reynolds number and the kind of pipe.

4— The practical diameters, i.e. the nearest manufacturers sizes available, are found for the above computed diameters.

5— The network is analysed for the practical diameters and required pressures using the following steps:

(a) The value of residual head "$\Delta H$" is calculated to the first node considered using equation (7).

\[ \Delta H = \frac{n \Sigma Q}{\Sigma Q/H} + Q_t \] \hspace{1cm} (7)

(b) The corrected head at the first node is evaluated using the following equation.

\[ H_N = H_{N_i} + H \]

Where $H_{N_i}$ & $H_{N_j}$ are the new and initial head respectively.

(c) Steps (a) & (b) are carried on the next node, and so on, using the latest values of the pressure at the nodes connected to it, to make one complete cycle of network-relaxation.

(d) The above relaxation process is continued until a stage is reached so that the residual head and flow at all the nodes is less than the allowables.

(e) The new flow in each pipe is calculated using Hazen-Williams's formula.

6 The new theoretical pipes diameters are computed for the required pressures and from the flows found in the previous step; hence the corresponding practical diameter are assigned.

7 The newly computed practical diameter is checked with the previously computed one for each pipe; if it is the same for each pipe then the results are printed, and if it is not, then steps from 5 to 7 are repeated.

Derivation of the Correction Formula

Consider the general head loss-flow formula:

\[ H = KQ^n \] \hspace{1cm} (3)

Where $H$ and $Q$ are the initial guesses of head loss and quantity in a pipe respectively, and the improved values are ($H + \Delta H$) and ($Q + \Delta Q$) then:

\[ H + \Delta H = K (Q + \Delta Q)^n \] \hspace{1cm} (4a)

* See next section for the derivation
\[ H + \Delta H = K Q n (1 + \frac{\Delta Q}{Q})^n \]  
\[ \text{(4b)} \]

Expanding by the binomial theorem:

\[ H + \Delta H = K Q^n (1 + n \frac{\Delta Q}{Q} + \frac{n(n-1)(\Delta Q)}{2!} \frac{Q}{Q} ) \]  
\[ \text{(5a)} \]

Assuming that \( \Delta Q \) is small compared with \( Q \), in other words that the initial assumed values for flows are nearly correct, the third and second terms may be neglected, then.

\[ H + \Delta H = K Q^n (1 + n \frac{\Delta Q}{Q}) \]  
\[ \text{(5b)} \]

\[ H + \Delta H = K Q^n + n Q K \frac{Q^n}{Q} \]  
\[ \text{(5c)} \]

Since \( H = K Q n \)

Then equ. (5c) becomes:

\[ H + \Delta H = H + n \Delta Q \frac{H}{Q} \]

\[ \Delta H = n \Delta Q \frac{H}{Q} \]

\[ H = \frac{n \Delta Q}{Q/H} \]  
\[ \text{(5d)} \]

The value of \( \Delta Q \) for each individual pipe is not known, but only for all pipes connected to a node (junction), so that

\[ H = \frac{n \Sigma Q}{\Sigma Q/H} \]  
\[ \text{(6)} \]

Equation (6) above is true when there is no draw-off or supply at the node, however if there is draw-off or supply (\( Q_t \)) at the node then the equation becomes

\[ H = \frac{n \Sigma Q}{\Sigma Q/H} + Q_t \]  
\[ \text{(7)} \]
Description of the Computer Program

The computer program developed consists of three parts. The main part in the analysis and design of the network, which is based on the method explained earlier. The other two parts are subprograms called at relevant intervals in the main program. The first sub-program is to select the practical size of diameter corresponding to the computed (theoretical) diameter: the practical sizes fixed are the currently known ones by engineers. New sizes can be added if desired. The second sub-program provides the graphical output of the results. The complete text of the main program is given in the next section.

Meaning of Parameters Used in the Computer Program

Input parameters:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>TITLE</td>
<td>title of the problem or project.</td>
</tr>
<tr>
<td>XN</td>
<td>value of n in the equation $H = KQ^n$.</td>
</tr>
<tr>
<td>NN</td>
<td>number of the nodes.</td>
</tr>
<tr>
<td>NUNIT</td>
<td>parameter refers to the type of units used</td>
</tr>
<tr>
<td>ALH</td>
<td>allowable (residual) head in each node.</td>
</tr>
<tr>
<td>ALQ</td>
<td>allowable (residual) flow in each node.</td>
</tr>
<tr>
<td>$N_1(I)$</td>
<td>no. of node.</td>
</tr>
<tr>
<td>$H(I)$</td>
<td>total pressure at the node.</td>
</tr>
<tr>
<td>$Q(I)$</td>
<td>quantity of draw-off or supply at the node.</td>
</tr>
<tr>
<td>$K_4(I)$</td>
<td>number of pipes incident at the node.</td>
</tr>
<tr>
<td>$E(I)$</td>
<td>elevation of the ground level at the node.</td>
</tr>
<tr>
<td>$V$</td>
<td>subscript of the above five parameters and refers to the node number under consideration.</td>
</tr>
<tr>
<td>$I,J$</td>
<td>subscripts in which I refers to the pipe number, J refers to the node number under consideration.</td>
</tr>
<tr>
<td>$N_2(I,J)$</td>
<td>the first node number.</td>
</tr>
<tr>
<td>$N_3(I,J)$</td>
<td>the second node number.</td>
</tr>
<tr>
<td>AL(I,J)</td>
<td>length of the pipe.</td>
</tr>
<tr>
<td>D(I,J)</td>
<td>diameter of the pipe.</td>
</tr>
<tr>
<td>C(I,J)</td>
<td>Hazen-William coefficient for the pipe.</td>
</tr>
</tbody>
</table>

Operation parameters:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>R(I,J)</td>
<td>value of K in general head loss equation $H = KQ^n$.</td>
</tr>
<tr>
<td>Q(I,J)</td>
<td>flow in the pipe.</td>
</tr>
<tr>
<td>Z(I,J)</td>
<td>value of the term $\frac{Q}{nH}$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>HH(JJ)</td>
<td>head loss between node under consideration (first node) and second node.</td>
</tr>
<tr>
<td>SUMZ</td>
<td>summation of parameter $Z(I,J)$ at the node.</td>
</tr>
<tr>
<td>SUMQ</td>
<td>algebraic sum of quantity at the node.</td>
</tr>
<tr>
<td>DH(JJ)</td>
<td>residual head at the node.</td>
</tr>
</tbody>
</table>
SUMQT(JJ) : algebraic sum of the term (SUMQ + QT(J)).
I,J : as defined in the input parameter section.
J,J : subscript which refers to the node number under consideration.
NC : number of relaxation cycles.

Text of the Computer Program

```
DIMENSION H(30),QT(30),K4(30),N2(7,30),N3(7,30),AL(7,30),Z(7,30),D1H(30),Q(7,30),D(7,30),C(7,30),R(7,30),N1(30),HI(30),SUMQT(30),EH(3,20),TITLE(20),AK(7,30),HL(7,30),HR(30),FD(7,30)
PI=3.1415
IC=0
NC=0
READ (2,3) (TITLE(I),I=1,20)
FORMAT (20A4)
READ (2,4) XN,NN,NUNIT,AL,H,ALQ,V
FORMAT (F10.0,215,3F10.0)
READ (2,2) (N2(I,J),N3(I,J),AL(I,J),C(I,J))
FORMAT (215,2F10.0)
CONTINUE
WRITE (3,30) (TITLE(I),I=1,20)
WRITE(3,3036)
```

11
12           WRITE(3,3033)
3033       FORMAT (23X, ' (FEET) ',10X, ' (CFS) ',17X, ' (FEET) ' )
            GO TO 14
21           WRITE(3,3035)
3035       FORMAT (23X, ' (FEET) ',10X, ' (GPM) ',17X, ' (FEET) ' )
            GO TO 14
13           WRITE(3,35)
35       FORMAT(22X, ' (METER) ',BX, ' (CU.M/H) ',LX, ' (METER) ' )
14           WRITE(3,3034) (N1(11),H(11),QT(11),K4(11),EH(11),11 = 1.NN)
3034       FORMAT(7X, 1 h, 7X.F10.3,4X, 1 5,3X.Fl 0.3)
            WRITE(3,4044)
4044       FORMAT ( / / /12X, 'FIRST NODE',SX, 'SECOND NODE',SX, 'LENTH ',KCV ,CY,'C' )
            IF(NUNIT-2)17,17,18
17           WRITE(3,4455)
4455       FORMAT(42X, ' (FEET) ' )
            GO TO 19
18           WRITE(3,4405)
4405       FORMAT(43X, ' (METER) ' )
19           DO 405 J = 1.NN
             K3=K4(J)
             IF(K3)7,405,7
7           DO 405 I = 1.K3
             WRITE(3,4055) N2(I,J),N3(I,J),AL(I,J),C(I,J)
4055       FORMAT(l2X.l 5,10 X,l 5,Fl6.2,5X.F6.2)
405 CONTINUE
1001         IF(NUNIT-2)31,25,26
25           DO 1001 J = 1.NN
             JJ=N1(J)
             QT(JJ)=QT(JJ) / 448.8
1001 CONTINUE
            GO TO 31
26           V = V *3.281
            DO 1002 J = 1.NN
             JJ=N1(J)
             K3=K4(J)
             H(JJ)=H(JJ) *3.281
             QT(JJ)=QT(JJ) *10.**3 / (3.785 *60. *448.8)
             IF(K3)8,1002,8
8           DO 1002 I = 1.K3
             AL(I,J)=AL(I,J) *3.281
1002 CONTINUE
31           DO 76 J = 1.NN

K3 = K4(J)
JJ = N1(J)
IF(K3)166,76,166
DO 76 I = 1, K3
AK(I,J) = 4.78 * AL(I,J) * (V * PI / (C(I,J) * 4.) ) * XN
76 CONTINUE
DO 175 J = 1, NN
JJ = N1(J)
K3 = K4(J)
HR(J) = H(JJ)
IF(K3)179,175,179
DO 175 I = 1, K3
K1 = N3(I,J)
HH(JJ) = H(JJ) - H(K1)
DIM = D(I,J) / 12.
R(I,J) = 4.78 * AL(I,J) / (C(I,J) * XN * DIM**4.87)
Q(I,J) = ABS(HH(JJ)) / R(I,J)**AA
D(I,J) = SQRT(4. * Q(I,J) / (PI**V))
DD = D(I,J)
CALL DIA(DD)
D(I,J) = DD
FD(I,J) = D(I,J)
175 CONTINUE
173 DO 180 J = 1, NN
JJ = N1(J)
K3 = K4(J)
IF(K3)171,180,171
DO 180 I = 1, K3
DIM = D(I,J) / 12.
R(I,J) = 4.78 * AL(I,J) / (C(I,J) * XN * DIM**4.87)
180 CONTINUE
1777 DO 80 J = 1, NN
K3 = K4(J)
JJ = N1(J)
IF(K3)10,89,10
DH(JJ) = 0.0
SUMQ(T(JJ)) = 0.0
GO TO 80
10 SUMQ = 0.0
SUMZ = 0.0
DO 20 I = 1, K3
K1 = N3(I,J)
20 CONTINUE
HH(JJ) = H(JJ) - H(K1)
R1 = ABS(HH(JJ))
R2 = R(I,J)
Q(I,J) = (R1 / R2) ** AA
IF(HH(JJ) > 70.800, 800
70
Q(I,J) = - Q(I,J)
SUMQ = SUMQ + Q(I,J)
GO TO 37
800
SUMQ = SUMQ + Q(I,J)
37
XX = XN * HH(JJ)
Z(I,J) = ABS(Q(I,J) / XX)
SUMZ = SUMZ + Z(I,J)
20
CONTINUE
DH(JJ) = -(SUMQ + QT(JJ)) / SUMZ
SUMQT(JJ) = SUMQ + QT(JJ)
H(JJ) = H(JJ) + DH(JJ)
80
CONTINUE
IF(IC - 0) 123, 123, 153
123
DO 4411 J = 1, NN
J = N1(J)
IF(ABS(SUMQT(JJ)) > 0.01) 4411, 4411, 1777
4411
CONTINUE
GO TO 411
153
DO 40 J = 1, NN
K3 = K4(J)
J = N1(J)
IF(ABS(DH(JJ)) > ALh) 45, 41, 41
45
IF(ABS(SUMQT(JJ)) > ALQ) 47, 41, 41
47
IF(K3) 3311, 40, 3311
3311
DO 40 I = 1, K3
IF(ABS(D(I,J) - FD(I,J)) > 0.1) 40, 40, 411
40
CONTINUE
GO TO 181
41
NC = NC + 1
GO TO 1777
411
NC = 0
IC = IC + 1
DO 5000 J = 1, NN
K3 = K4(J)
J = N1(J)
H(JJ) = HR(JJ)
IF(K3) 5001, 5000, 5001
5001
DO 5000 I = 1, K3
FD(I,J) = D(I,J)
K1 = N3(I,J)
HILL = HR(J) - HR(K1)
D(I,J) = (4.87 * AL(I,J) * ABS(Q(I,J)) * XN / (C(I,J) * XN * ABS(HILL))) * (1 / 4.87)
DD = D(I,J)
CALL DIA(DD)
D(I,J) = DD
5000 CONTINUE
GO TO 173
181 WRITE(3,300)
300 FORMAT(1HI, / / / /10X.42(' ' ' '), / /18X. 'RESULTS OF THE DESIGN'
  / / /10X.42 ( ' ' '), / / )
WRITE(3,6005) IC,NC
6005 FORMAT(10X. 'NUMBER OF DESIGN CYCLES ' = ' .15, /10X. 'NUMBER OF
  RELAXATION CYCLES ' = ' .15)
WRITE(3,111)
111 FORMAT(10X. 'VALUES OF THE RESIDUAL HEAD AND FLOW AT THE'
NODES ' ',1 / .10X.49(' ' '), / )
WRITE(3,121)
121 FORMAT(10X. 'NODE ',10X. 'DH (FT) ' ,8X. 'SUMQT (CFS) ' ,4X. 'STATE OF'
NODE IS ' ')
DO 1000 J = 1,NN
K3 = K4(J)
11 JJ = N1(J)
IF(K3)11,1000,11
11 IF(ABS(SUMQT(JJ)) - ALQ <= 999.777.777)
999 WRITE(3,866)JJ,DH(JJ),SUMQT(JJ)
866 FORMAT(6X.16,5X.14.6,5X.14.6,7X, 'BALANCED ' )
GO TO 1000
777 WRITE(3,555)JJ,DH(JJ),SUMQT(JJ)
555 FORMAT(6X.16,5X.14.6,5X.14.6,5X, 'UNBALANCED ' )
1000 CONTINUE
WRITE(3,302)
302 FORMAT(1 / / / /25X. 'PRESSURE AT THE NODES ' ,/.25X.21(' ' ' '), / )
WRITE(3,3221)
221 FORMAT(24X, 'REQUIRED PRESSURES ' ,12X. 'COMPUTED PRESSURES ' ,/.10X.
 ' NO 1DE ' ,9X. ' TOTAL ' ,8X. 'HYDRAULIC ' ,8X. 'TOTAL ' ,9X. ' HYDRAULIC '
 ' ,/.21X. 'PRESSURE ' ,7X. 'PRESSURE ' ,6X. 'PRESSURE ' ,8X. 'PRESSURE ' )
IF(NUNIT = 2)42.42,22.5
42 WRITE(3,22)
22 _FORMAT (21X. ' (FEET) ' ,9X. ' (FEET) ' ,9X. ' (FEET) ' ,9X. ' (FEET) ' , / )
GO TO 43
WRITE(3,23)
FORMAT(19X. ' (METER) ' .8X. ' (METER) ' .8X. ' (METER) ' .8X. ' (METER) ' ,/)
DO 102 J = 1, NN
JJ = N1(J)
K3 = K4(JJ)
IF(NUNIT - 2) 126, 126, 127
H(JJ) = H(JJ) / 3.281
HR(JJ) = HR(JJ) / 3.281
HP = H(JJ) - EH(JJ)
HPR = HR(JJ) - EH(JJ)
WRITE(3, 24) JJ, HR(JJ), HPR, H(JJ), HP
WRITE(3, 15.4) JJ
WRITE(3, 15.3)
WRITE(3, 311)
FORMAT( / / /20X. ' FLOW AND HEAD LOSS IN EACH PIPELINE'. /)
WRITE(3, 28)
FORMAT( / 10X. ' FIRST NODE ' .2X. ' SECOND NODE ' .5X. ' K ' .10X. ' DISCHARGE ' .3 1X. ' HEAD LOSS ' .3X. ' DIAMETER ' )
IF(NUNIT - 2) 51, 52, 53
WRITE(3, 62)
FORMAT(51X. ' (CFS) ' .6X. ' (FEET) ' .6X. ' (INCH) ' ,/)
GO TO 54
WRITE(3, 29)
FORMAT(51X. ' (GPM) ' .6X. ' (FEET) ' .6X. ' (INCH) ' ,/)
GO TO 54
WRITE(3, 63)
FORMAT(49X. ' (CU.M./H) ' .4X. ' (METER) ' .7X. ' (CM) ' ,/)
DO 101 J = 1, NN
K3 = K4(J)
JJ = N1(J)
IF(K3), 16, 101, 16
DO 101 I = 1, K3
K1 = N3(I, J)
HL(I, J) = H(JJ) - H(K1)
IF(NUNIT - 2) 99, 44, 55
Q(I, J) = (Q(I, J) * 4.488.8)
GO TO 99
Q(I, J) = Q(I, J) * 3.785 * 60. ** 3 * 448.8
D(I, J) = D(I, J) * 2.5
IF(N2(I, J) - N3(I, J) - 108, 108, 103
JK = N3(I, J)
IF(K4(JK) 101, 103, 101
WRITE(3, 38) N2(I, J), N3(I, J), R(I, J), Q(I, J), HL(I, J), D(I, J)
Input Data & Computer Output

The input data for the program are: the constant n (usually for turbulent flow = 1.85), number of nodes, the type of units parameter (Metric or British)*, allowable residual head and flow, the design velocity of flow. Also the input data should include the pressure and draw-off (or supply) at each node, the nodes-connection, the length and Hazen-Williams coefficient for each pipe.

The output results will include the diameter, head loss and discharge in each pipe for the specified requirements.

The rest of this section illustrates the sequence of the input data required and the layout of the computer output for the example network shown below (fig. 1). Node number (1) represents a reservoir with constant supply head of 100 feet, in such cases the number of pipes connected the node should be denoted by "O".

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* The program can accept any one of the following sets of units:
  (a) L in ft., d in inches, flow cfs; (ie NUNIT fed = 1)
  L in ft., d in inches, flow gpm; (ie NUNIT fed = 2)
  L in M., d in cm. flow cu.m/hr (ie NUNIT fed = 3)
THE CONSTANT N = 1.850
NO OF NODES = 5
TYPE OF UNIT USED = 2
ALLOWABLE RESIDUAL HEAD = 0.1
ALLOWABLE RESIDUAL FLOW = 0.001
DESIGN VELOCITY = 4.00

<table>
<thead>
<tr>
<th>NODE</th>
<th>INITIAL GUESS OF TOTAL PRESSURE (FEET)</th>
<th>DRAW-OFF (SUPPLY) (GPM)</th>
<th>NUMBER OF PIPES</th>
<th>GROUND LEVEL (FEET)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100.000</td>
<td>0.000</td>
<td>0</td>
<td>0.000</td>
</tr>
<tr>
<td>2</td>
<td>90.000</td>
<td>1000.000</td>
<td>3</td>
<td>0.000</td>
</tr>
<tr>
<td>3</td>
<td>85.000</td>
<td>3000.000</td>
<td>2</td>
<td>0.000</td>
</tr>
<tr>
<td>4</td>
<td>87.000</td>
<td>2000.000</td>
<td>3</td>
<td>0.000</td>
</tr>
<tr>
<td>5</td>
<td>92.000</td>
<td>3000.000</td>
<td>2</td>
<td>0.000</td>
</tr>
</tbody>
</table>

FIRST NODE SECOND NODE LENGTH (FEET) C (HAZEN)

<table>
<thead>
<tr>
<th>FIRST NODE</th>
<th>SECOND NODE</th>
<th>LENGTH (FEET)</th>
<th>C (HAZEN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1</td>
<td>2500.0</td>
<td>120.00</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>1000.0</td>
<td>120.00</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>800.0</td>
<td>120.00</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>1000.0</td>
<td>120.00</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>500.0</td>
<td>120.00</td>
</tr>
<tr>
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<td>2</td>
<td>800.0</td>
<td>120.00</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>500.0</td>
<td>120.00</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>300.0</td>
<td>120.00</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>1200.0</td>
<td>120.00</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>300.0</td>
<td>120.00</td>
</tr>
</tbody>
</table>

RESULTS OF THE DESIGN

NUMBER OF DESIGN CYCLES = 2
NUMBER OF RELAXATION CYCLES = 19

* The type 2 refers flow in gpm., length in ft, diameter in inches, pressure in ft, head loss in ft and velocity in ft/sec.
VALUES OF THE RESIDUAL HEAD AND FLOW AT THE NODES

<table>
<thead>
<tr>
<th>NODE</th>
<th>RESIDUAL HEAD (FT)</th>
<th>RESIDUAL FLOW (CFS)</th>
<th>STATE OF NODES</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.426894E-03</td>
<td>-0.514030E-03</td>
<td>BALANCED</td>
</tr>
<tr>
<td>3</td>
<td>0.544899E-03</td>
<td>-0.762939E-03</td>
<td>BALANCED</td>
</tr>
<tr>
<td>4</td>
<td>0.435957E-03</td>
<td>-0.928878E-03</td>
<td>BALANCED</td>
</tr>
<tr>
<td>5</td>
<td>0.170952E-03</td>
<td>-0.259399E-03</td>
<td>BALANCED</td>
</tr>
</tbody>
</table>

PRESSURE AT THE NODES

<table>
<thead>
<tr>
<th>NODE</th>
<th>TOTAL PRESSURE (FEET)</th>
<th>HYDRAULIC PRESSURE (FEET)</th>
<th>COMPUTED PRESSURES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>TOTAL PRESSURE</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>HYDRAULIC PRESSURE</td>
</tr>
<tr>
<td>1</td>
<td>100.000</td>
<td>100.000</td>
<td>100.000</td>
</tr>
<tr>
<td>2</td>
<td>90.000</td>
<td>90.000</td>
<td>90.000</td>
</tr>
<tr>
<td>3</td>
<td>85.000</td>
<td>85.000</td>
<td>85.399</td>
</tr>
<tr>
<td>4</td>
<td>87.000</td>
<td>87.000</td>
<td>87.326</td>
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<tr>
<td>5</td>
<td>92.000</td>
<td>92.000</td>
<td>92.696</td>
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</table>

FLOW AND HEAD LOSS IN EACH PIPELINE

<table>
<thead>
<tr>
<th>FIRST NODE</th>
<th>SECOND NODE</th>
<th>'K' in H=KQ</th>
<th>DISCHARGE (GPM)</th>
<th>HEAD LOSS (FEET)</th>
<th>DIAMETER (INCH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>3</td>
<td>0.236221E00</td>
<td>-3372.773</td>
<td>-9.857</td>
<td>18.00</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>0.680680E00</td>
<td>-1261.669</td>
<td>-4.742</td>
<td>12.00</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>0.544544E00</td>
<td>-1091.019</td>
<td>-2.816</td>
<td>12.00</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>0.160650E00</td>
<td>-1718.415</td>
<td>1.926</td>
<td>14.00</td>
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<tr>
<td>5</td>
<td>1</td>
<td>0.678768E01</td>
<td>5627.816</td>
<td>-7.303</td>
<td>20.00</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td>0.204204E00</td>
<td>2527.700</td>
<td>5.370</td>
<td>12.00</td>
</tr>
</tbody>
</table>

Automatic-Graphical Results

In order to simplify further the examination of the desired network by the computer: A sub-program which provides the plotting of the network configuration with the complete results is developed and can be called at if desired. No doubt the use of this sub-program will increase the computer time consumed. This should be balanced against the time required by the engineer to transfer the tabulated results on the network diagram. In many cases this facility proved to be economical besides being the eliminator of human error in transferring the tabulated results on to the network diagram.

Figure (2A) is an example network with specified boundary conditions. The input data was fed for
This network and using the computer program described the complete design for the network was obtained automatically as shown in figure (2B). It can be noted that the final pressures at the nodes are slightly different from the specified ones. This is automatically done to make up for obtaining possible sizes of diameters rather than unavailable sizes.
Conclusions:

The growth of many new cities and the easy access to digital computers have imposed the importance of developing methods for the design of pipe networks.

This article demonstrated a simple and versatile method for sizing the pipe networks according to consumer demands. The computer program discussed proved its simplicity, both in input data required and output results. The program has been tested for various networks and no difficulties have been encountered. However, if new standard pipe sizes are manufactured then slight alteration on the program must be made. The equations used are those for water; if the program is to be used for other fluids, such as gasses, then the basic equation for the head loss against discharge should be altered and a complete new testing for the program is required.

REFERENCES

9 — Stucky. A.T. "Methods used for the Analysis of Pipe Networks".

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