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THE VARIATION OF FRICTIONAL AND SEPARATION LOSSES WITH SYSTEM COMPLEXITY IN WATER DISTRIBUTION TO A GROUP OF BUILDINGS

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Abstract: By progressively increasing the number of buildings supplied from a water reservoir at a fixed elevation, fractions of the total head loss which account for the loss due to friction and through fittings are derived for the varying system complexity. The fractions due to friction vary from 0.807 to 0.686 with a corresponding variation from 0.193 to 0.314 of the fractions due to fittings, as the length of the first index pipe run increases from 68.0m to 122.9m with corresponding increases in the number of appliances supplied from 17 to 68 and in the total water flow rate from 0.88L/s to 2.35L/s. The component fractions are useful for estimating head losses in water distribution networks for groups of buildings.
Keywords: Head loss fractions, friction and fittings, groups of buildings.

1. INTRODUCTION

The total head loss in gravity-flow water distribution systems comprises of frictional losses and losses through pipe fittings such as elbows, tees, reducers and valves.

The frictional head loss per metre run of pipe has been derived from the Hazen-Williams formula (utilizing a Hazen-Williams Coefficient C = 140, for plastic pipe material) as (Sodiki, 2002)

$$h_f = 1.1374 \, x \, 10^{-3 d^{-4.867}} \; q^{1.85} \quad (1)$$

where d = pipe diameter (m)

and q = flow rate (m^3/s)

Thus, the selection of a suitable pipe diameter depends on the frictional loss per metre run and the flow rate; and graphical presentations of the form of Equation 1 abound in the literature (Institute of Plumbing, 1977 and Barry, 1984).

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Furthermore, the head loss through pipe fittings is usually expressed in terms of a loss coefficient k of the fitting as (Sodiki, 2004)

$$h_p = 0.08256kd^{-4}q^2 \qquad (2)$$

Values of k for common pipe fittings are given as (Giles, 1977) 0.75 for elbows, 2.0 for tees and 0.25 for gate valves. Values for reducers are usually given in terms of the ratio of upstream diameter d_1 to downstream diameter d_2, as in Table 1 (Giles, 1977). The values of k, so obtained, are referred to the downstream diameter to obtain h_p from Equation 2.

In an earlier paper (Sodiki and Orupabo, 2011), fractions of the total loss which account for the loss due to friction, and through fittings, were derived for varying complexities of pipe work in water distribution to a range of sanitary appliances within a building. The present paper intends to derive fractions for water distribution to a group of buildings.

Pipe work complexity is expressed, in turn, in terms of length of first index pipe run, number of appliances supplied, and total water discharge from the reservoir.

2. SYSTEM DESCRIPTION

The selected water distribution system is gravity-fed from an elevated storage which supplies four bungalows in a residential estate. Each bungalow contains 17 sanitary appliances, made up of 5 water closets, 5 wash basins, 2 bath tubs, 3 water heaters, 1 shower tray and 1 kitchen sink. The site layout is shown in Figure 1. In order to understand the variation of the frictional loss and the loss through pipe fittings, with the varying complexity of pipe work, the distribution system is conceptualized into the four independent forms shown in Figures 1 to 4. The pipe work complexity is found to decrease in the order of Figure 1, 2, 3 to 4.

Analyses are carried out on the first index pipe run from the elevated storage, for each form, and comparisons are made. The first index pipe run is the farthest run from the storage and is that which is most likely to be starved of water at its end, due to low system pressure.

The distribution system of Figure 4 (which is the least complex) is utilized to illustrate the analysis by which the results for the other forms were also obtained. An isometric sketch of the pipe work of Figure 4 is given in Figure 5 in which the parameters of the different pipe sections are given using boxes placed near the sections. The number to the top of the box is the measured pipe length (in metres), while that to the bottom is the flow rate through the section (in litres per second).

3. ANALYSIS OF HEAD LOSS COMPONENTS

Rather than using complicated mathematical analyses, a more practical graphical method of pipe sizing and determining frictional losses is utilized. Losses through pipe fittings are determined from Equation 2.

By the graphical method, loading units (Institute of Plumbing, 1977 and Barry, 1984) for each sanitary appliance (which are taken as 2 for a water closet, 1.5 for a wash basin, 10 for a bath tub, 2 for a water heater, 3 for a shower and 3 for a kitchen sink) are utilized, to account for the non-simultaneous discharge from all the installed appliances. The cumulative discharge units for the different pipe sections are entered in the graph of loading units versus flow rates of Figure 6 (Institute of Plumbing, 1977) to obtain the respective flow rates. For loading units below 10 with corresponding flow rates less than 0.34L/s (for which Figure 6 cannot be used) linear extrapolations are utilized by the equation

$$\text{Design flow} = \frac{0.34}{10}\ \mathbf{X}\ \text{loading unit} \qquad (3)$$

The elevation difference between the distribution pipe outlet at the water reservoir and the highest sanitary appliance supplied is the available static head and is maintained at 3.2m for all the distribution configurations considered.

Measured length of the first index run for Figures 4 and 5 = 68.0m

Therefore, permissible maximum frictional head loss per metre run (H/L) that must not be exceeded in selecting any pipe size = $\frac{3.2}{68.0} = 0.047$

Utilizing this H/L value and the sectional flow rates, pipe sizes are selected from the graph of Figure 7 (Institute of Plumbing, 1977). For instance, for the main supply section A to B which has a flow rate of 0.88L/s, a 40mm pipe is selected; at point A in Figure 7, where the actual H/L value obtained at the intersection of the lines of flow rate and pipe diameter is 0.024. Multiplying this value by the measured length of the pipe section (which is 24.0m) gives the frictional head loss of this section as 0.576.

The pipe section designations, loading units, design flow rates, pipe lengths, permissible maximum H/L value, pipe sizes, actual H/L values and frictional losses, obtained in a similar manner for all pipe sections, are entered, respectively, in Columns 1 to 8 of Table 2.

Having obtained the pipe sizes, locations of reducers are indicated. These are entered in Column 9. Other types of pipe fitting (i.e. elbows, tees and valves) in the first index run which are specified in consideration of system functionality are listed in Column 10.

Now, in pipe section G to I, for instance, there are 1 number 25mm x 20mm reducer (which has d_1/d_2 = 1.25), 4 elbows,1 gate valve and 1 tee. By interpolation in Table 1, *k* for the reducer is 0.1025. Then, from Equation 2,

$$h_p \text{ for pipe section G to I} = (0.1025 + 4 x 0.75 + 0.25 + 2) x$$

$$0.08256 x 0.02^{-4} x (0.12 x 10^{-3})^2$$

$$= 0.04m$$

The head loss through fittings, so obtained for the different pipe sections, are entered in Column 11 of Table 2.

It is thus observed that the total head loss through friction and that due to fittings for the first index pipe run of the system of Figures 4 and 5 are, respectively, l.657m and 0.397m.

By carrying out the foregoing analysis for the other systems (Figure 3, 2 and 1), the results in Tables 3 to 5 are, respectively, obtained.

4. DISCUSSION OF RESULTS

The losses due to friction and fittings for all the analyzed systems are summarized in Table 6 which also shows the fractions of these losses that constitute the total loss, for the varying system complexities.

Graphical presentations (using ‘Excel’) are given in Figures 8 to 10 to show the variation of the head loss components with system complexity.

Within the limits of the utilized values of the variables, the graphs show a decrease of the frictional loss fraction and an increase of the fraction of loss through fittings, with increasing system complexity. Furthermore, second order relationships are depicted for the variations of the ratio of loss through fittings to the total loss, and the different measures of system complexity.

Within the limits of system complexity utilized in the analyses, the frictional loss fraction varies from 0.807 to 0.686 with a corresponding variation from 0.193 to 0.314 of the fraction of head loss due to fittings.

These fractions are useful in estimating the different head loss components. For instance, for a given length of index pipe length, number of appliances served, or total discharge from the reservoir; and for a given storage elevation, the total head loss can quickly be estimated by adding the relevant fraction due to fittings to the frictional head loss.

5. CONCLUSIONS

Within the limits of pipe work complexity used in the analyses, the fraction of head loss due to friction decreases with a corresponding increase of the fraction due to fittings, for water distribution to a group of buildings. The fractions are useful in the analysis of system pressures, in such situations as in determining storage elevations and pump head requirements.

Water distribution systems for larger groups of buildings, such as are utilized in town distribution networks could also be analyzed by the same method.

REFERENCES

1. Barry, R. (1984), The Construction of Buildings Vol. 5: Supply and Discharge Services, Granada Publishing Ltd., London.

2. Giles, R. V. (1977), Fluid Mechanics and Hydraulics, McGraw-Hill Book Co., New York

3. Institute of Plumbing (IOP) (1977), Plumbing Services Design Guide, IOP, Essex.

4. Sodiki, J. I. (2002), A Representative Expression for Swimming Pool Circulator Pump Selection, Nigerian Journal of Engineering Research and Development, Vol. 1, No. 4, Pp. 24-35.

5. Sodiki, J. 1. (2004), Computer Generation of Total System Heads for Submersible Pumps in Boreholes, Compendium of Engineering Monographs, Vol. 1, No. 1, Pp. 1-12.

6. Sodiki, J. 1. and Orupabo, S. (2011), Estimating Head and Frictional Losses Through Pipe Fittings in Building Water Distribution Systems, Journal of Applied Science and Technology, Vol. 16, Nos 1 & 2, 2011, 67-74.

Table 1: Values of K for Reducers (Giles, 1977)

d_1/d_2*	k
1.2	0.08
1.4	0.17
1.6	0.26
1.8	0.34
2.0	0.37
2.5	0.41
3.0	0.43
4.0	0.45
5.0	0.46

* d_1 = upstream diameter, d_2 = downstream diameter

Table 2: Calculations for Pipe Sizing and Head Loss Components for Water Distribution to One Bungalow

1	2	3	4	5	6	7	8	9	10	11
Pipe Section No	Loading Units	Design Flow (L/s)	Pipe length (m)	Permissible maximum H/L	Diameter (mm)	Actual H/L	Frictional head loss, $h_{friction}$ (m)	Reducers (mm x mm)	Fittings (other than reducers)	Loss through fittings, $h_{fittings}$ (m)
A to B	49.5	0.88	24.0	0.047	40	0.024	0.576	-	3elbows 2 gate valves 1 tee	0.119
B to C	46.0	0.85	3.6	0.047	40	0.023	0.083	-	1 tee	0.047
C to D	41.0	0.80	3.4	0.047	40	0.020	0.068	-	1 tee	0.041
D to F	25.5	0.50	12.4	0.047	32	0.023	0.285	40 **X** 32	1 elbow 1 tee	0.056
F to G	19.0	0.43	5.6	0.047	25	0.045	0.252	32 **X** 25	1 tee	0.083
G to I	3.5	0.12	17.0	0.047	20	0.019	0.323	25 **X** 20	4 elbows 1 gate valve 1 tee	0.040
I to J	1.5	0.05	2.0	0.047	15	0.035	0.070	20 **X** 15	3 elbows 1 gate valve	0.011
			68.0				1.657			0.397

Table 3: Calculations for Pipe Sizing and Head Loss Components for Water Distribution to Two Bungalows

1	2	3	4	5	6	7	8	9	10	11
Pipe Section No	Loading Units	Design Flow (L/s)	Pipe length (m)	Permissible maximum H/L	Diameter (mm)	Actual H/L	Frictional head loss, $h_{friction}$ (m)	Reducers (mm x mm)	Fittings (other than reducers)	Loss through fittings, $h_{fittings}$ (m)
A to B	99.0	1.35	24.0	0.035	50	0.013	0.312	-	3elbows 2 gate valves 1 tee	0.114
B to C	95.5	1.30	3.6	0.035	50	0.012	0.043	-	1 tee	0.045
C to D	90.5	1.25	3.4	0.035	50	0.011	0.037	-	1 tee	0.041
D to F	75.0	1.10	12.4	0.035	50	0.010	0.124	-	1 elbow 1 tee	0.044
F to G	68.5	0.98	5.6	0.035	40	0.030	0.168	50 x 40	1 tee	0.065
G to H	53.0	0.90	4.0	0.035	40	0.025	0.100	-	1 tee	0.052
H to K	49.5	0.88	8.0	0.035	40	0.024	0.192	-	1 gate valve 1 tee	0.056
K to L	25.5	0.50	7.0	0.035	32	0.023	0.161	40 x 32	1 tee	0.041
L to M	19.0	0.43	5.6	0.035	32	0.017	0.095	-	1 tee	0.029
M to N	3.5	0.12	17.0	0.035	20	0.019	0.323	32 x 20	4 elbows 1 gate valves 1 tee	0.041
N to O	1.5	0.05	2.0	0.035	15	0.035	0.070	20 x 15	3 elbows 1 gate valve	0.011
			92.6				1.625			0.539

Table 4: Calculations for Pipe Sizing and Head Loss Components for Water Distribution to Three Bungalows

1	2	3	4	5	6	7	8	9	10	11
Pipe Section No	Loading Units	Design Flow (L/s)	Pipe length (m)	Permissible maximum H/L	Diameter (mm)	Actual H/L	Frictional head loss, $h_{friction}$ (m)	Reducers (mm x mm)	Fittings (other than reducers)	Loss through fittings, $h_{fittings}$ (m)
A to B	148.5	1.85	24.0	0.033	50	0.0200	0.480	-	3 elbows 2 gate valves 1 tee	0.215
B to C	145.0	1.80	3.6	0.033	50	0.0190	0.068	-	1 tee	0.086
C to D	140.0	1.75	3.4	0.033	50	0.0180	0.061	-	1 tee	0.081
D to E	124.5	1.70	6.1	0.033	50	0.0175	0.107	-	1 tee	0.076
E to P	49.5	0.88	17.2	0.033	40	0.0240	0.413	50 x 40	1 gate valve 1 tee	0.028
P to Q	46.0	0.82	3.6	0.033	40	0.0220	0.079	-	1 tee	0.043
Q to R	41.0	0.80	3.4	0.033	40	0.0200	0.068	-	1 tee	0.041
R to S	25.5	0.50	12.4	0.033	32	0.0230	0.285	40 x 32	1 elbow 1 tee	0.056
S to T	19.0	0.43	5.6	0.033	32	0.0170	0.095	-	1 tee	0.029
T to V	3.5	0.12	17.0	0.033	20	0.0190	0.323	32 x 20	4 elbows 1 gate valve 1 tee	0.041
V to R	1.5	0.05	2.0	0.033	20	0.0045	0.009	-	3 elbows 1 gate valve	0.003
			98.3				1.988			0.699

Table 5: Calculations for Pipe Sizing and Head Loss Components for Water Distribution to Four Bungalows

1	2	3	4	5	6	7	8	9	10	11
Pipe Section No	Loading Units	Design Flow (L/s)	Pipe length (m)	Permissible maximum H/L	Diameter (mm)	Actual H/L	Frictional head loss, h_{friction} (m)	Reducers (mm x mm)	Fittings (other than reducers)	Loss through fittings, h_{fittings} (m)
A to B	198.0	2.35	24.0	0.026	65	0.0100	0.240	-	3 elbows 2 gate valves 1 tee	0.121
B to C	194.5	2.30	3.6	0.026	65	0.0090	0.032	-	1 tee	0.049
C to D	189.5	2.25	3.4	0.026	65	0.0080	0.027	-	1 tee	0.047
D to E	174.0	2.20	6.1	0.026	50	0.0250	0.153	65 x 50	1 tee	0.136
E to P	99.0	1.35	17.2	0.026	50	0.0130	0.224	-	1 gate valve 1 tee	0.054
P to Q	95.5	1.30	3.6	0.026	50	0.0120	0.043	-	1 tee	0.045
Q to R	90.5	1.25	3.4	0.026	50	0.0110	0.037	-	1 tee	0.041
R to S	75.0	1.10	12.4	0.026	50	0.0100	0.124	-	1 elbow 1 tee	0.044
S to T	68.5	0.98	5.6	0.026	50	0.0090	0.050	-	1 tee	0.025
T to U	53.0	0.90	4.0	0.026	40	0.0250	0.010	50 x 40	1 tee	0.055
U to X	49.5	0.88	8.0	0.026	40	0.0240	0.192	-	1 gate valve 1 tee	0.056
X to Y	25.5	0.50	7.0	0.026	32	0.0230	0.161	40 x 32	1 tee	0.041
Y to Z	19.0	0.43	5.6	0.026	32	0.0170	0.095	-	1 tee	0.029
Z to Y^1	3.5	0.12	17.0	0.026	20	0.0190	0.323	32 x 20	4 elbows 1 gate valve 1 tee	0.041
Y^1 to Z^1	1.5	0.05	2.0	0.026	20	0.0045	0.009	-	3 elbows 1 gate valve	0.003
			122.9				1.720			0.787

Table 6: Head Loss Components for Varying Complexities

1	2	3	4	5	6	7	8
Figure Number	Length of 1st Index Pipe Run (m)	No. of Appliances Served by Main Distribution Pipe	Total Water Discharge from Reservoir (L/s)	Frictional Loss in 1st Index Run (m)	Loss through Fittings in 1st Index Run (m)	Ratio of Frictional Loss to Total Loss	Ratio of Loss through Fittings to Total Loss
4 and 5	68.0	17	0.88	1.657	0.397	0.807	0.193
3	92.6	34	1.35	1.625	0.539	0.751	0.249
2	98.3	51	1.85	1.988	0.699	0.740	0.260
1	122.9	68	2.35	1.720	0.787	0.686	0.314

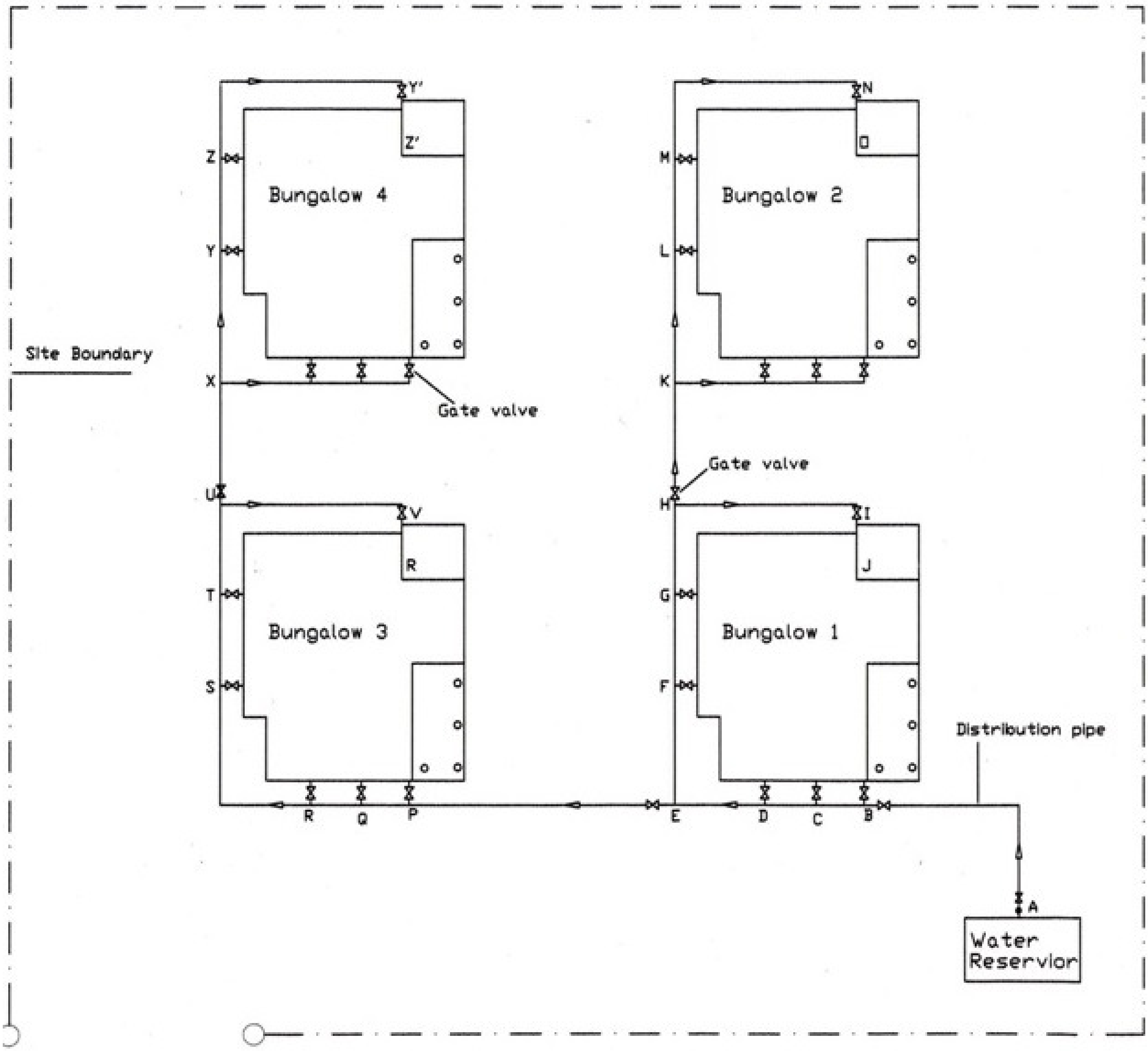

Figure 1: Distribution Layout to Four Bungalows

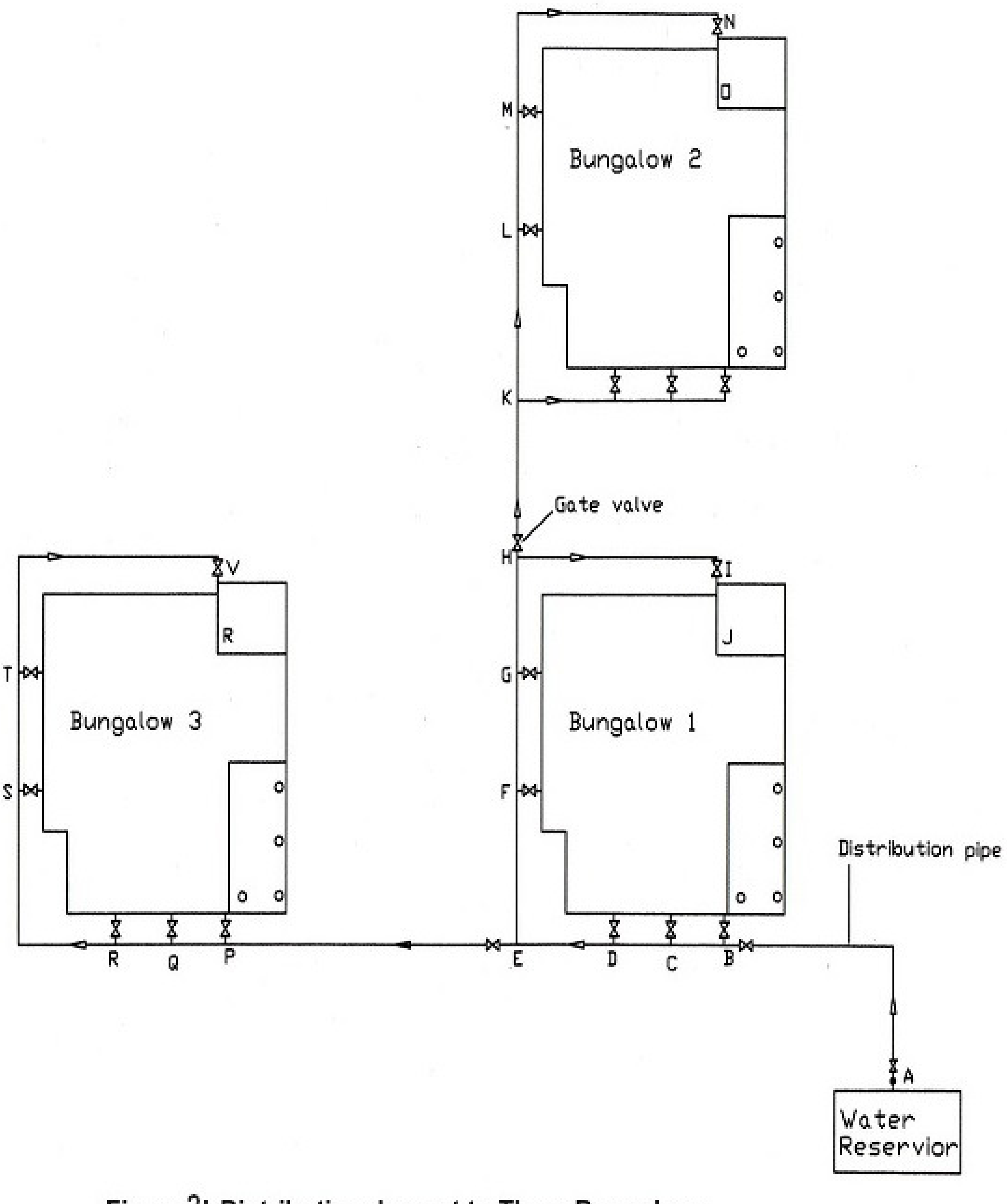

Figure 2: Distribution Layout to Three Bungalows

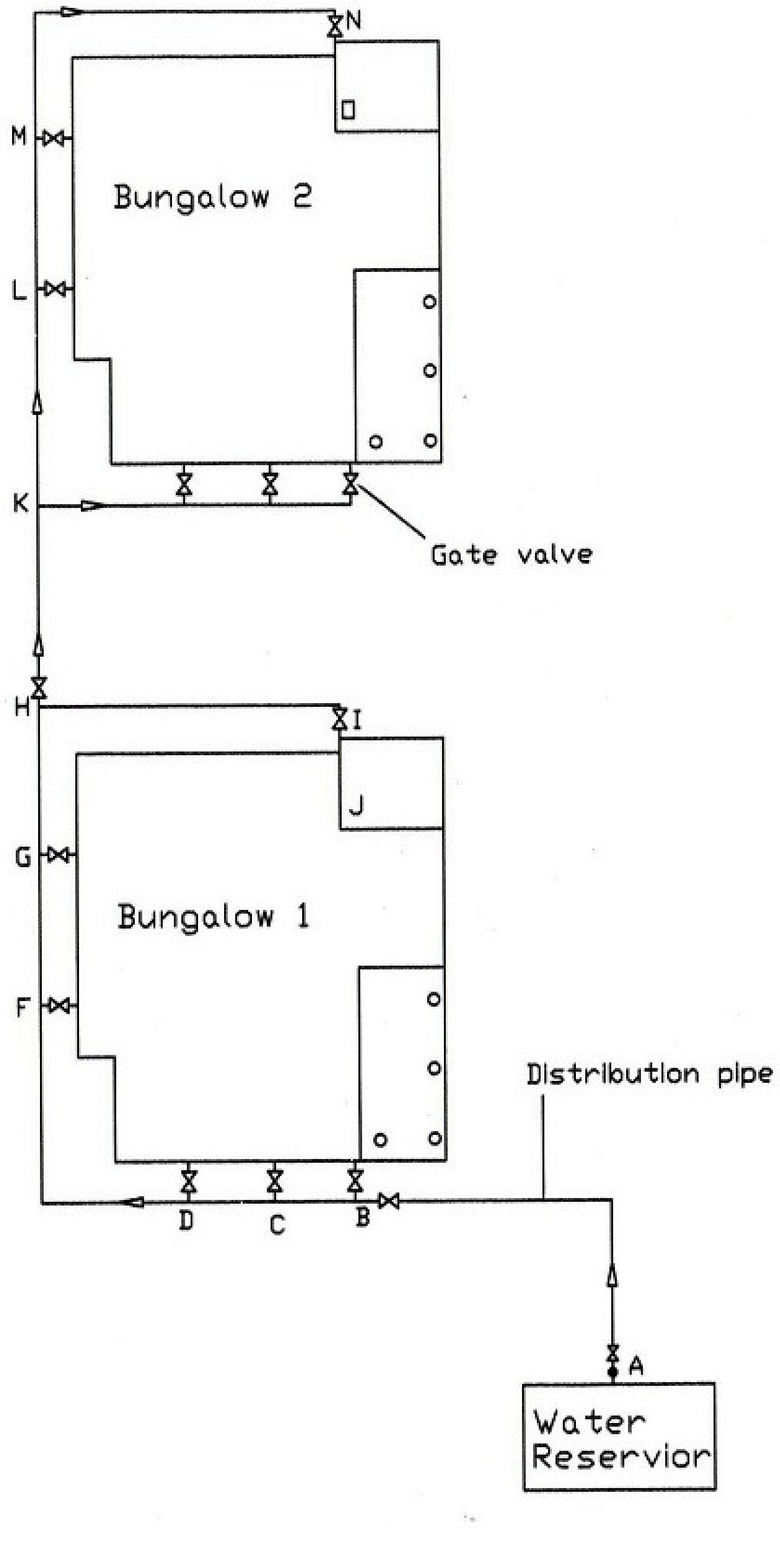

Figure 3: Distribution Layout to Two Bungalows

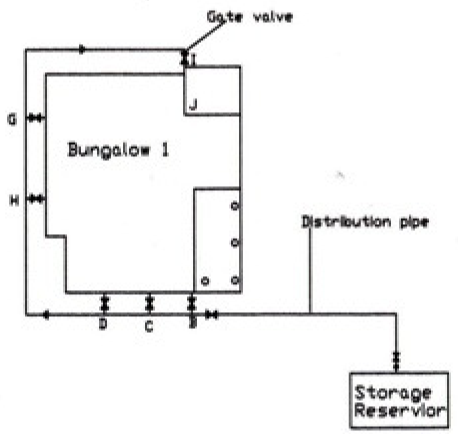

Figure 4 : Distribution Layout to One Bungalow

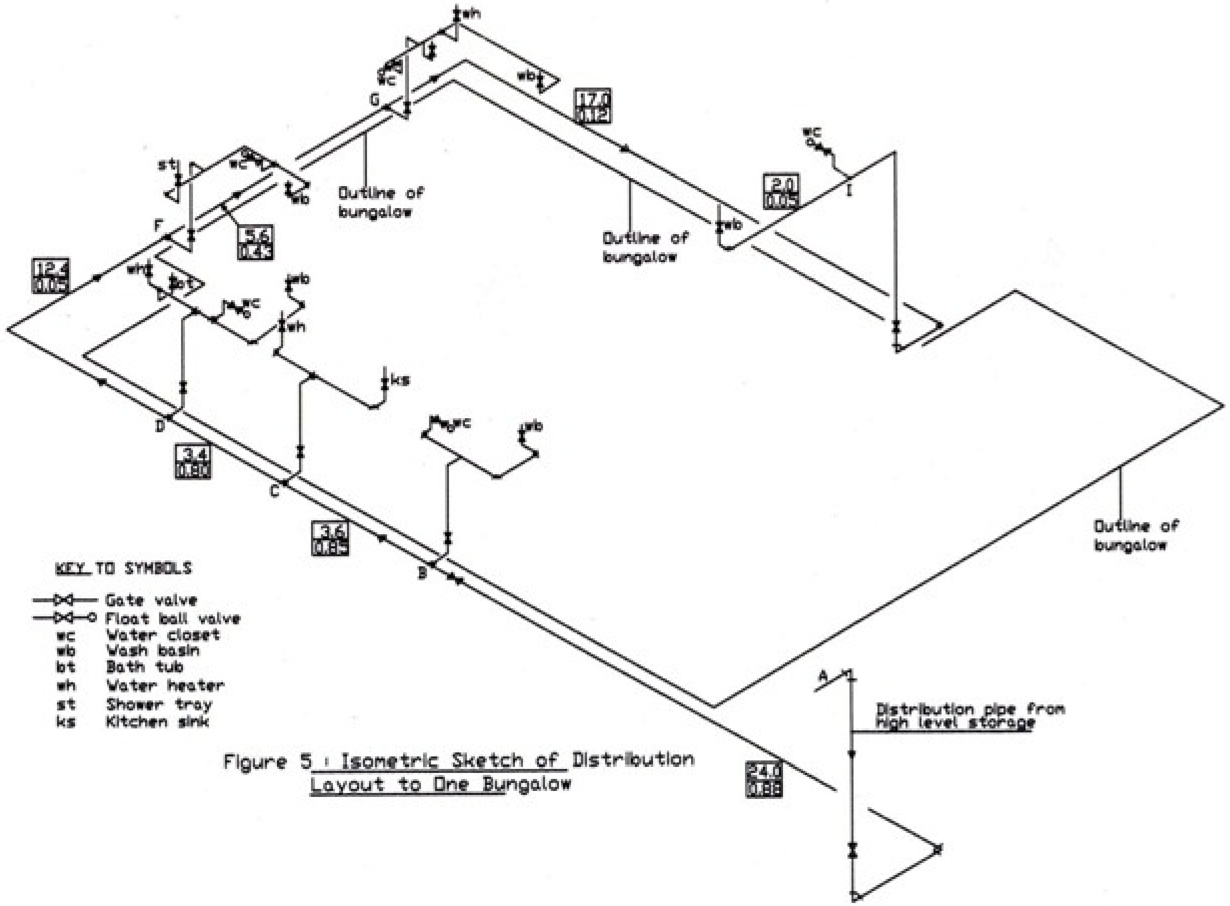

Figure 5 : Isometric Sketch of Distribution Layout to One Bungalow

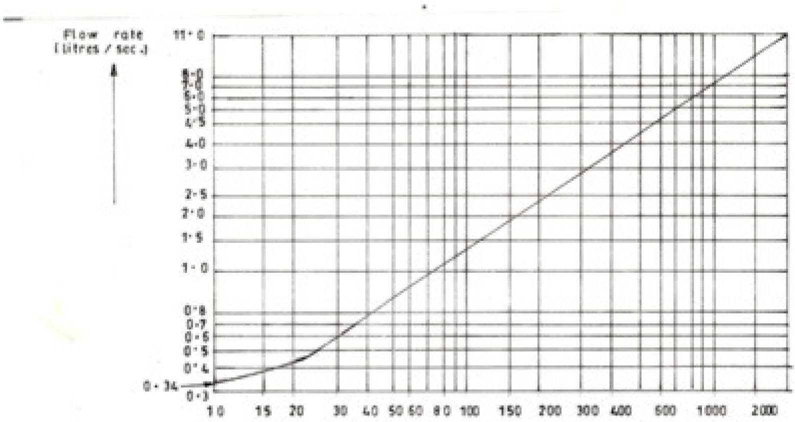

Figure 6: Graph of Loading Unit Versus Flow Rate
(Institute of Plumbing, 1977)

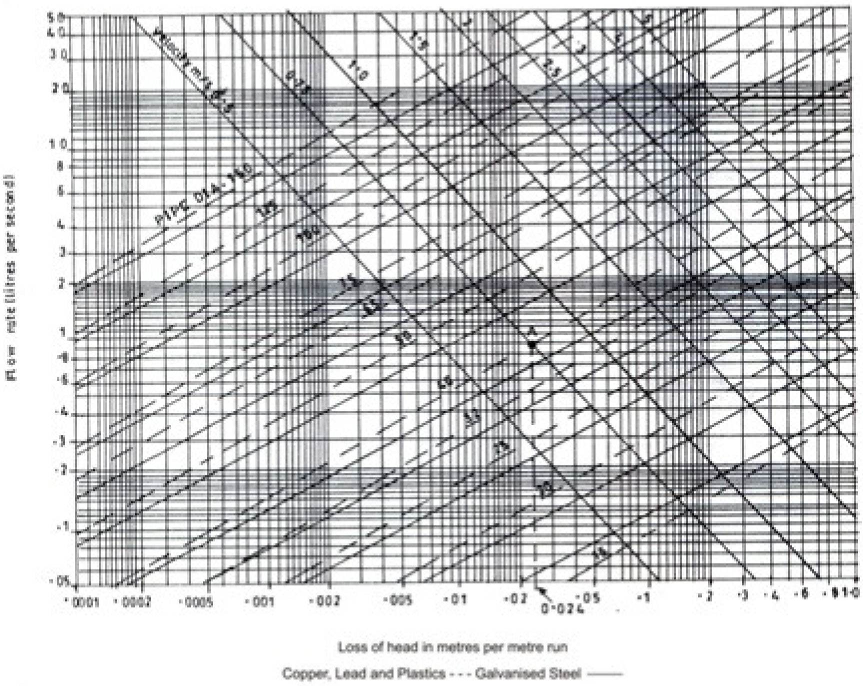

Figure 7: Pipe Sizing Graph
(Institute of Plumbing, 1977)

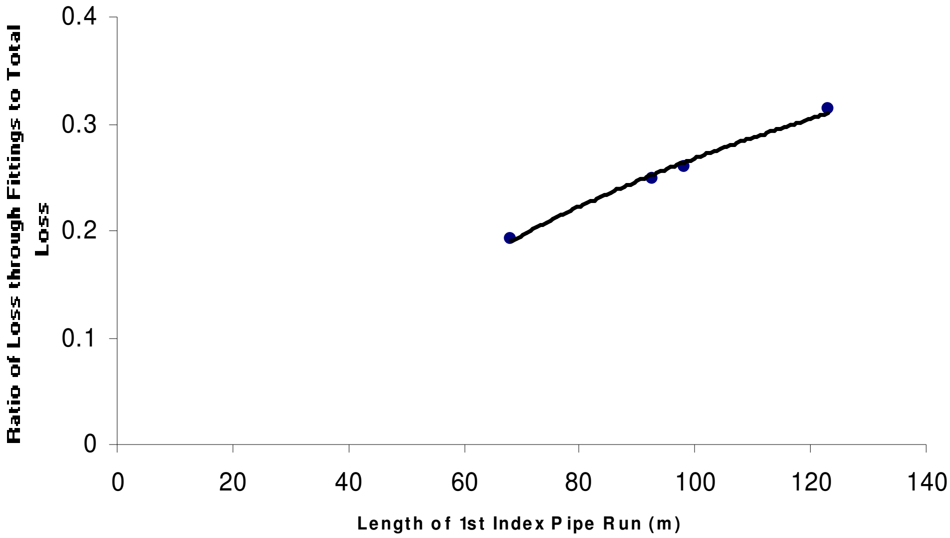

Fig. 8: Length of Index Pipe Run Versus Fraction of Loss Through Fittings

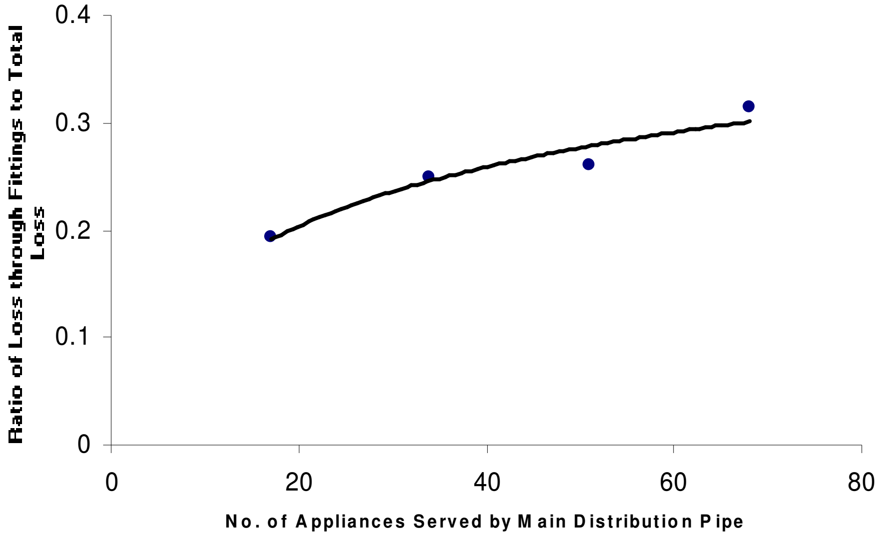

Fig. 9: No. of Appliances Served Versus Fraction of Loss Through Fittings

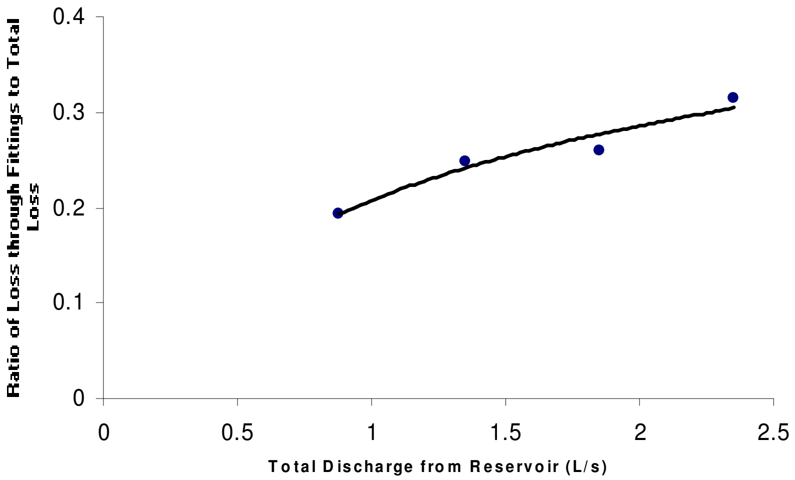

Fig. 10: Total Water Discharge Versus Fraction of Loss Through Fittings