A COMPARISON OF CALCULATED AND MEASURED PRESSURES IN BUILDING WATER DISTRIBUTION SYSTEMS

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ABSTRACT

Common methods of pipe selection and pressure loss (hence, remaining pressure) calculations were utilized on two existing water distribution systems. Also, physical pressure measurements were taken at selected points in the distribution systems for comparison with the calculated values. Results of scatter plots and correlation analysis show good agreement between the calculated and measured pressures. The results, thus, validate the calculation procedures.

Keywords: Hazen-Williams Formula, D'Arcy-type Equation, Pipe Sizing Chart, Pressure Guage Readings**.**

INTRODUCTION

A good estimate of the pressure losses due to friction and pipe fittings (and, hence, the remaining pressure at various points in the system) is required in water distribution system design, as this estimate facilitates the determination of an appropriate reservoir elevation and pump head requirements.

One common method of estimating the frictional loss h_f is the use of the Hazen-Williams formula, expressed in terms of readily measurable variables as (Sodiki, 2002)

$$h_f = \frac{10.62}{C^{1.85}} l d^{-4.867} q^{1.85} \qquad \text{- - - (1)}$$

where l = pipe length in m^3/s
d = pipe diameter in m^3/s
q = mean flow rate in m^3/s
and C = Hazen-Williams coefficient of relative roughness of the pipe material

Expressing Equation 1 in terms of head loss per metre run of pipe gives

$$\frac{h_f}{l} = \frac{10.62}{C^{1.85}} d^{-4.867} q^{1.85} \qquad \text{- - - (2)}$$

Equation 2 being expressed in 'pipe sizing graphs' or 'friction charts' as a plot of h_f/l against q makes it easier to obtain d, and hence other parameters (such as the flow velocity) of the relevant pipe section.

The head loss through fittings is commonly obtained by the D'Arcy – type equation (Douglas et al, 1995; Giles, 1977)

$$h_p = k\frac{v^2}{2g} \qquad \text{- - - (3)}$$

where k is a loss coefficient of the fitting, given as 0.75 for an elbow, 0.25 for a gate valve and 2 for a tee (Douglas et al, 1995; Giles, 1977). $v$is the mean flow velocity and g is the gravitational acceleration. Table 1 gives $k$values of reducers in terms of ratios of upstream diameter d_1 to downstream diameter d_2 (Giles, 1977).

Substituting for v as

$$v = \frac{4q}{\pi d^2} \qquad \text{- - - (4)}$$

and $g = 9.81 m/s^2$yields

$$h_p = 0.08256\ k\, d^{-4} q^2 \qquad \text{- - - (5)}$$

Table 1: Values of K for Reducers, in Terms of Ratio of Upstream Diameter (d_1) to Downstream Diameter (d_2) (Giles, 1977)

Ratio 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

Thus, with a knowledge of k, d and q for a given fitting the head loss through each fitting is obtained.

The total head loss values (frictional and through fittings) and, thereby, remaining heads in different pipe sections of two existing distribution configurations were calculated. Physical measurements were subsequently taken with a pressure guage at selected points in the two systems. The measured pressures were compared with the calculated values by utilizing scatter plots between the two sets of values, for each of the two distribution configurations. Furthermore, the correlation coefficients between the calculated and measured pressures were computed for each of the two distribution systems. This comparison tests the validity of the calculation procedures.

ANALYSIS OF FIRST DISTRIBUTION SYSTEM

Figures 1 and 2 show the water distribution system plans, while Figure 3 shows the isometric sketch of the layout. In Figure 3, the pipe sections are numbered using boxes which touch the pipe sections as follows: the cumulative loading units are on the top of the box while the measured pipe section lengths are on the bottom. The loading units are quantities which take into account the non-simultaneous use of all installed appliances (Giles, 1977; Barry, 1984) and are used for obtaining design flow rates from the graph of Figure 4. These units are 2 for

a water closet cistern, 1.5 for a wash basin, 10 for a bath, 4 for a sink, and 2 for a water heater cistern, 3 for a shower and 1.5 for a bidet (Giles, 1977; Barry, 1984). Hence, for pipe section, 5 - 15 which carries 15.5 cumulative loading units, the corresponding flow rate is 0.39 l/s.
The lowest value of loading units for which Figure 4 can be used is 10, with a corresponding design flow rate of 0.34 l/s, and linear extrapolations below this value are made for very small units according to the relation

Design flow (in l/s) = 0.34/10 (or 0.034) x loading units - - - (6)

Table 2 gives a summary of the pipe size selection, and calculation of the pressure losses and remaining pressures.

Now, the elevated tank is at a height of 9.3m above ground level and the height of the water heater supply at pipe section 9 – 10 (which is the final section of the first index run) is 5.4m above ground.

∴ head H available for distribution in the first index run = 9.3 – 5.4 = 3.9m.
Measured length L of first index run 0-10 = 43.4m.

Thus, permissible rate of head loss per metre run (H/L) that must not be exceeded in the index run = 3.9/43.4 = 0.09

Pipe sizes are selected from the graph of Figure 5 (Barry, 1984) using this maximum H/L value and the respective design flow rates. For pipe section 5 - 15, for instance, which has a flow rate of 0.39 l/s, a 25mm pipe is selected. The actual H/L value at the point of intersection of the lines of the flow rate and the pipe size is 0.042. Multiplying the actual H/L value by the measured pipe length of 0.5m gives a frictional head loss of 0.021m. The pipe section designations, loading units, design flow rates, pipe lengths, pipe diameters, actual H/L values and frictional losses are entered, respectively, in Columns 1 to 7 of Table 2.

Pipe fittings and valves are normally placed in the distribution system such as to achieve proper functionality and are indicated in Column 8 of Table 2. Locations and sizes of reducers are indicated by the selected pipe diameters and entered in Column 9.

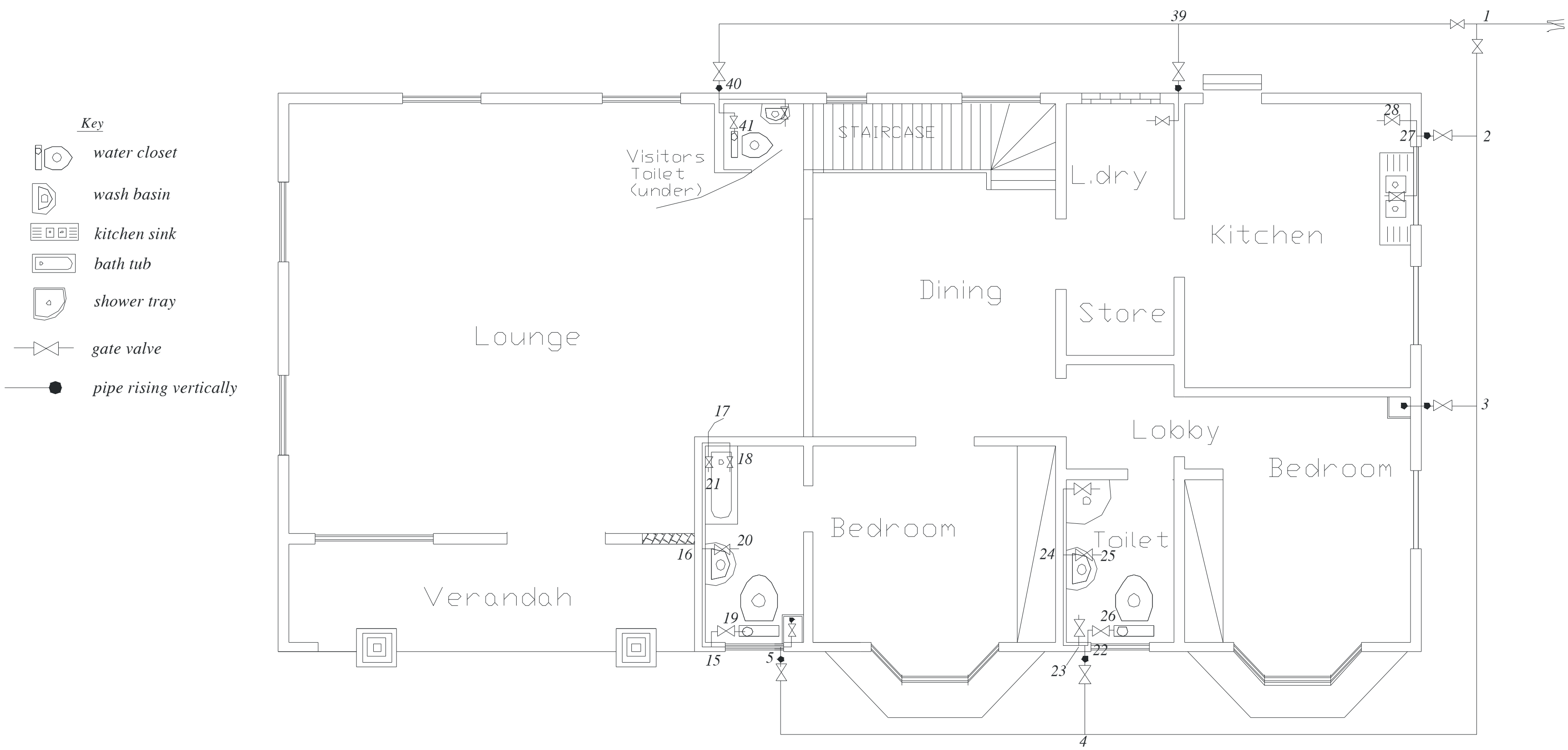

Figure 1: Ground Floor Plan of First Distribution System

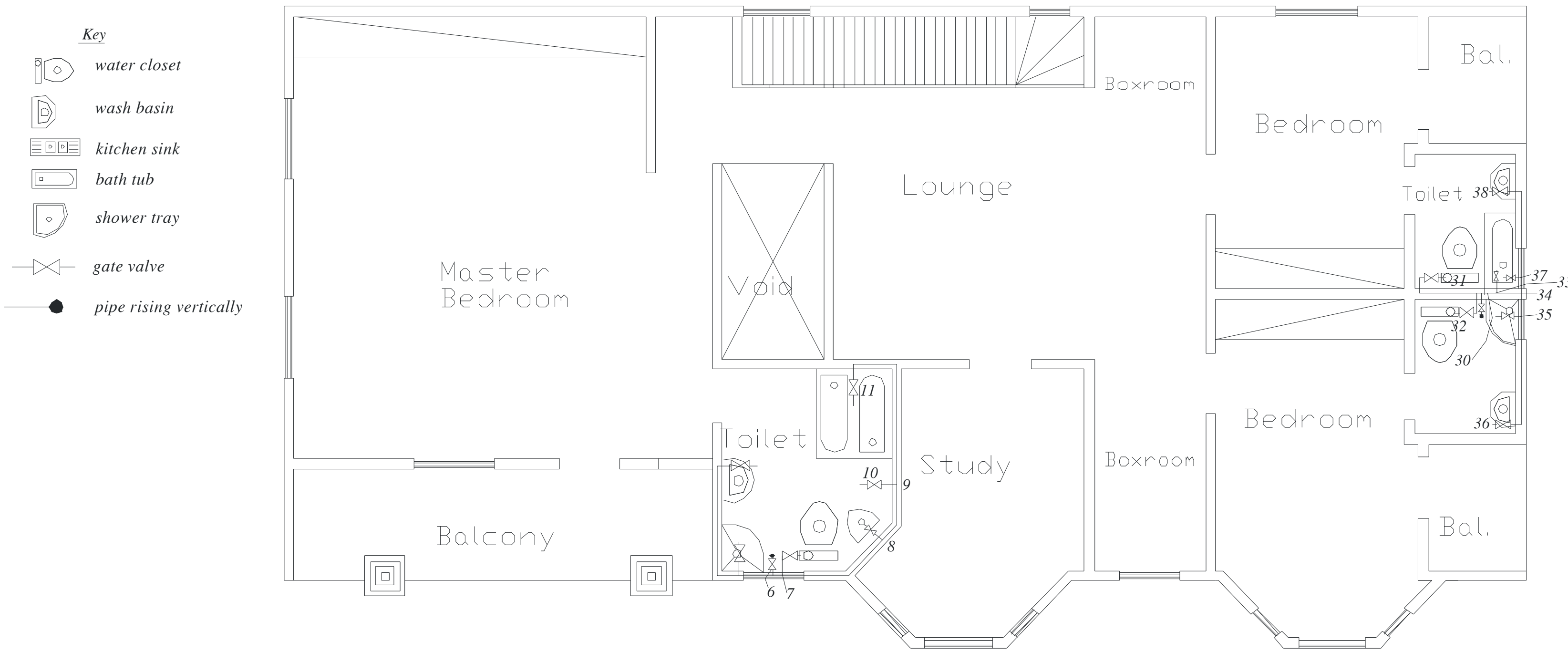

Figure 2: First Floor Plan of First Distribution System

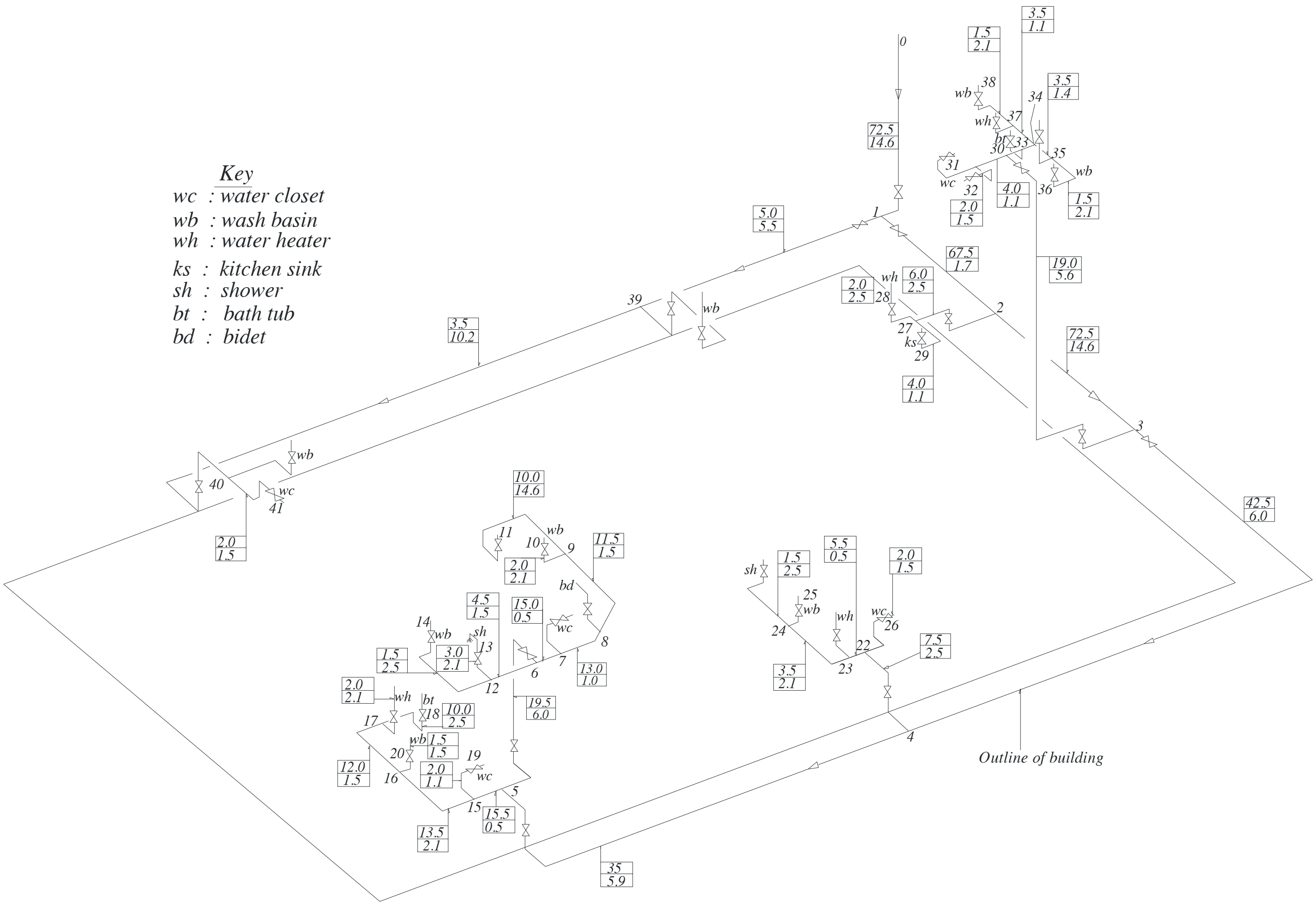

Figure 3: Isometric Sketch of First Distribution System

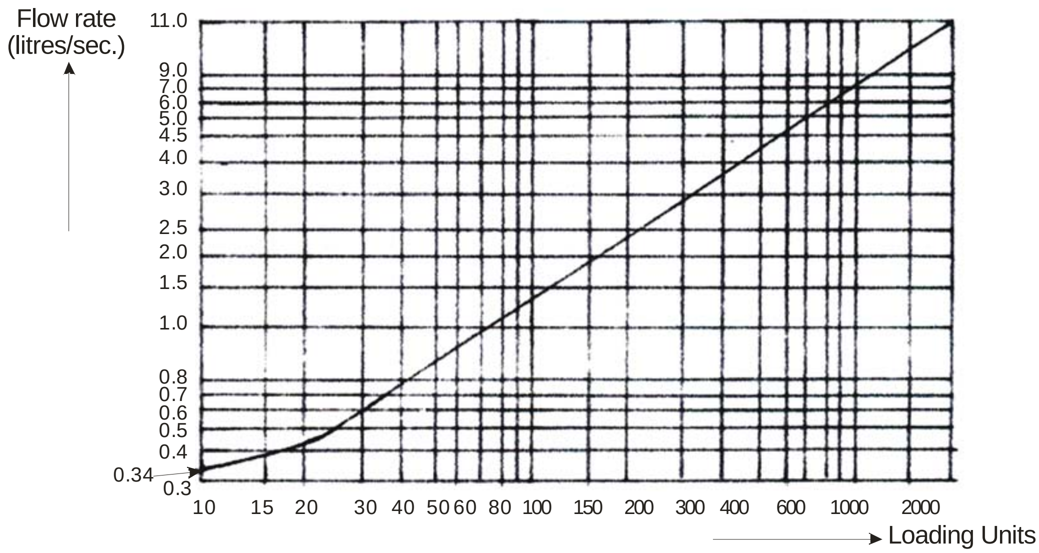

Figure 4: Graph of Loading Unit Versus Flow Rate (Institute of Plumbing ,1977)

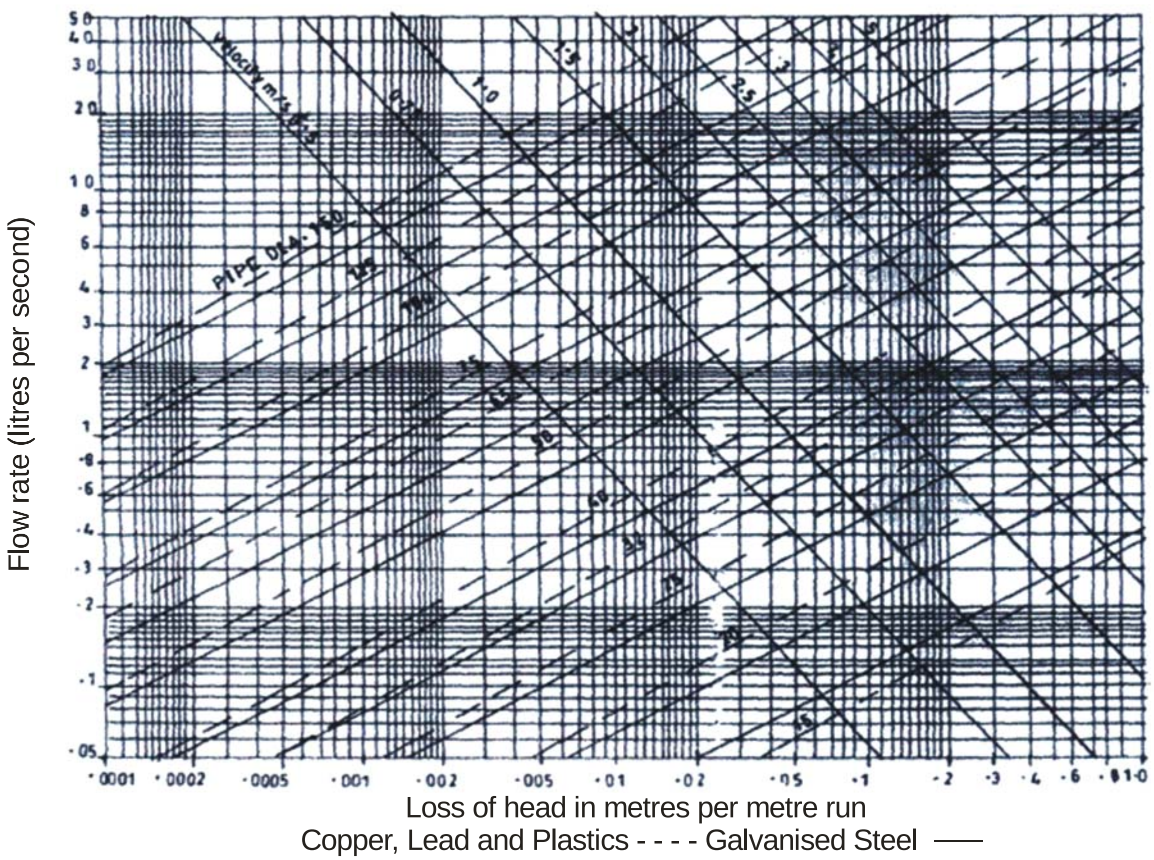

Figure 5: Pipe Sizing Graph (Institute of Plumbing, 1977)

Table 2: Summary of Pipe Sizing, Head Loss and Remaining Head Calculations, and Guage Readings for First Distribution System

1	2	3	4	5	6	7	8	9	10	11	12	13	14
Pipe Section No.	Loading Units	Design Flow rate (l/s)	Measured Pipe Length (m)	Diameter (mm)	Actual H/L Value	Frictional Head Loss (m)	Types and Nos. of Fittings and Valves (Other than Reducers)	Reducers (mm x mm)	Head Loss due to Fittings and Valves (m)	Total Head Loss (m)	Remaining Head at Test point (m)	Remaining Head at Test point (bar)	Pressure Gauge Reading at Test Point (bar)
0-1	72.5	1.05	14.6	32	0.085	1.241	1g.v, 1 tee	-	0.195	1.436	12.264	1.20	1.3
1-2	67.5	1.00	1.7	32	0.070	0.119	1g.v, 1tee	-	0.177	0.296	11.968	1.17	-
2-3	61.5	0.95	4.1	32	0.065	0.267	1 tee	-	0.136	0.403	11.565	1.13	-
3-4	42.5	0.73	6.0	32	0.040	0.240	1 elbow, 1 tee	-	0.115	0.355	11.210	1.10	-
4-5	35.0	0.64	5.9	25	0.085	0.502	3 elbow, 1g.v., 1 tee	32 x 25	0.399	0.901	10.309	1.01	-
5-6	19.5	0.46	6.0	25	0.050	0.300	3 elbow, 2g.v, 1 tee	-	0.203	0.503	9.806	0.96	1.0
6-7	15.0	0.40	0.5	25	0.043	0.022	1 tee	-	0.068	0.090	9.716	0.95	-
7-8	13.0	0.37	1.0	25	0.035	0.035	1 elbow, 1 tee	-	0.080	0.115	9.601	0.94	-
8-9	11.5	0.35	1.5	25	0.030	0.045	1 elbow, 1 tee	-	0.071	0.116	9.485	0.93	-
9-10	1.5	0.05	2.1	15	0.017	0.036	4 elbow, 1g.v.	25 x 15	0.014	0.061	9.424	0.92	-
9-11	10.0	0.34	2.0	20	0.028	0.056	1 elbow, 1 tee	25 x 20	0.066	0.122	9.363	0.92	0.9
6-12	4.5	0.15	1.5	20	0.030	0.045	1 tee, 1g.v,	25 x 20	0.027	0.072	9.734	0.95	-
12-13	3.0	0.10	2.1	15	0.080	0.168	1 elbow, 1g.v.	20 x 15	0.019	0.187	9.547	0.94	-
12-14	1.5	0.05	2.5	15	0.017	0.043	3 elbow, 1g.v.	20 x 15	0.011	0.079	9.655	0.95	1.1
5-15	15.5	0.39	0.5	25	0.042	0.021	1 tee	-	0.075	0.097	10.212	1.00	-
15-16	13.5	0.38	2.1	25	0.038	0.080	1 elbow, 1 tee	-	0.031	0.111	10.101	0.99	-
16-17	12.0	0.36	1.5	25	0.033	0.050	1 elbows, 1tee	-	0.028	0.078	10.023	0.98	-
17-18	10.0	0.34	2.5	20	0.028	0.070	3 elbows, 1g.v.	25 x 20	0.156	0.226	9.797	0.96	-
15-19	2.0	0.07	1.1	15	0.045	0.050	2 elbows, 1g.v.	25 x 15	0.016	0.066	10.146	0.99	1.0
16-20	1.5	0.05	1.5	15	0.017	0.026	1 elbows, 1g.v.	25 x 15	0.005	0.046	10.055	0.99	-
17-21	2.0	0.07	2.1	15	0.045	0.095	1elbows, 1g.v.	25 x 15	0.010	0.105	9.918	0.97	1.1
22-23	5.5	0.19	0.5	20	0.045	0.023	1tee	-	0.037	0.060	10.835	1.06	-
23-24	3.5	0.12	2.1	20	0.022	0.046	1 elbows, 1tee	-	0.020	0.066	10.769	1.06	-
24-25	1.5	0.05	2.5	15	0.017	0.043	1 elbows, 1g.v.	20 x 15	0.005	0.073	10.696	1.05	1.0
22-26	2.0	0.07	1.5	15	0.045	0.068	3 elbows, 1g.v.	20 x 15	0.021	0.089	10.806	1.06	1.1
2-27	6.0	0.20	2.5	20	0.050	0.125	2 elbows, 1g.v.	32 x 20	0.041	0.166	11.802	1.16	-
27-28	2.0	0.07	2.5	15	0.045	0.113	2 elbows, 1g.v.	20 x 15	0.015	0.128	11.174	1.14	-
27-29	4.0	0.14	1.1	20	0.030	0.033	2 elbows, 1g.v.	-	0.018	0.051	11.751	1.15	-
3-30	19.0	0.45	5.6	25	0.049	0.074	4 elbows, 2g.v., 1 tee	32 x 25	0.240	0.514	11.051	1.11	1.1
30-31	4.0	0.14	1.1	20	0.030	0.033	1 tee	25 x 20	0.021	0.054	10.997	1.08	-
31-32	2.0	0.07	1.5	15	0.045	0.068	2 elbows, 1 g.v.	20 x 15	0.015	0.083	10.914	1.07	1.0
30-33	17.0	0.43	0.5	25	0.045	0.023	1 tee	25 x 20	0.082	0.105	10.946	1.07	-
33-34	7.0	0.24	1.5	20	0.060	0.090	1 tee	-	0.059	0.149	10.797	1.06	-
34-35	3.5	0.12	1.1	20	0.022	0.024	1 tee	-	0.015	0.039	10.758	1.06	-
35-36	1.5	0.05	2.1	15	0.017	0.036	2 elbows, 1 g.v.	20 x 15	0.008	0.065	10.693	1.05	1.0
34-37	3.5	0.12	1.1	20	0.022	0.024	1 tee	-	0.015	0.039	10.758	1.06	-
37-38	1.5	0.05	2.1	15	0.017	0.036	2 elbows, 1g.v.	20 x 15	0.008	0.065	10.693	1.05	-
1-39	5.0	0.17	5.5	20	0.003	0.165	1g.v., 1 tee	32 x 20	0.037	0.202	12.062	1.18	-
39-40	3.5	0.12	10.2	20	0.022	0.224	3 elbows, 1g.v, 1 tee	-	0.033	0.261	11.801	1.16	1.2
40-41	2.0	0.07	1.5	15	0.045	0.068	3 elbows, 1g.v,	20 x 15	0.021	0.089	11.712	1.15	-
4-22	7.5	0.26	2.5	20	0.070	0.175	2 elbows, 1g.v, 1 tee	32 x 20	0.140	0.315	10.895	1.07	-

Now, in pipe section 4-5 which carries a flow rate of 0.64 l/s and is of 25mm diameter, for instance, there are 3 elbows, 1 gate valve, 1 tee and 1 (32mm x 25mm) reducer (with d_1/d_2 = 1.28).

Applying Equation 5 to obtain the loss due to fittings for pipe section 4-5

$$h_p = 0.08256\ \{(3\times 0.75)+(1\times 0.25)+(1\times 2)+(1\times 0.116)\}\times 0.025^{-4}\times\left(0.64\times 10^{-3}\right)^2 = 0.399m$$

where the k value for the reducer is obtained by interpolation in Table 1 as 0.116.

The types and numbers of pipe fittings (other than reducers), the sizes and locations of reducers, and the head loss due to fittings for each pipe section are, respectively, entered in Columns 8, 9, and 10; while Columns 11, 12 and 13 show, respectively, the total head loss (frictional and that due to fittings), the remaining head in metres of water, and the remaining head in bar. The pressure guage readings (in bar) at selected test points in the distribution system are listed in Column 14.

Table 3 further summarizes the calculated and measured pressures at the test points, together with the parameters for computing the correlation coefficient between the two sets of pressures. The scatter plot of Figure6 shows a positive correlation.

Table 3: Parameters for Computing the Correlation Coefficient between Calculated and Measured Pressures for First Distribution System

Test Point (in Figure 7)	Calculated Pressure at Test Point(bar) (x_i)	Measured Gauge Pressure at Test Point (bar) (y_i)	$x_i - \bar{x}$ (bar)	$y_i - \bar{y}$ (bar)	$(x_i - \bar{x})(y_i - \bar{y})$ (bar^2)	$(x_i - \bar{x})^2$ (bar^2)	$(y_i - \bar{y})^2$ (bar^2)
1	1.20	1.3	0.16	0.22	0.0352	0.0256	0.0484
6	0.96	1.0	-0.08	-0.08	0.0064	0.0064	0.0064
10	0.92	0.9	-0.12	-0.18	0.0216	0.0144	0.0324
14	0.95	1.1	-0.09	0.02	-0.0081	0.0081	0.0004
19	0.99	1.0	-0.05	-0.08	0.0040	0.0025	0.0064
21	0.97	1.1	-0.07	0.02	-0.0014	0.0049	0.0004
25	1.05	1.0	0.01	-0.08	-0.0008	0.0001	0.0064
26	1.06	1.1	0.02	0.02	0.0004	0.0004	0.0004
30	1.11	1.1	0.07	0.02	0.0014	0.0049	0.0004
32	1.07	1.1	0.03	0.02	0.0006	0.0009	0.0004
36	1.05	1.0	0.01	-0.08	-0.0008	0.0001	0.0064
40	1.16	1.2	0.12	0.12	0.0144	0.0144	0.0144
	$\sum = 12.49$	$\sum = 12.90$			$\sum = 0.0729$	$\sum = 0.0827$	$\sum = 0.1228$
	$\bar{x} = 1.04$	$\bar{y} = 1.08$					

Now, the correlation coefficient r between the calculated pressures (designated as x) and measured pressures (designated as y)may be obtained as (Lipson and Seth, 1973)

$$r = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\left[\sum(x_i - \bar{x})^2 \sum(y_i - \bar{y})^2\right]^{1/2}} \qquad - - - (7)$$

where x_i = ith value of calculated pressure

$\bar{x}$ = mean value of calculated pressure

y_i = ith value of measured pressure

$\bar{y}$ = mean value of measured pressure

Substituting the values from Table 3

$$r = \frac{0.0729}{\sqrt{0.0827 \times 0.1228}} = 0.723 = 72.3\%$$

$$r^2 = 52.3\%$$

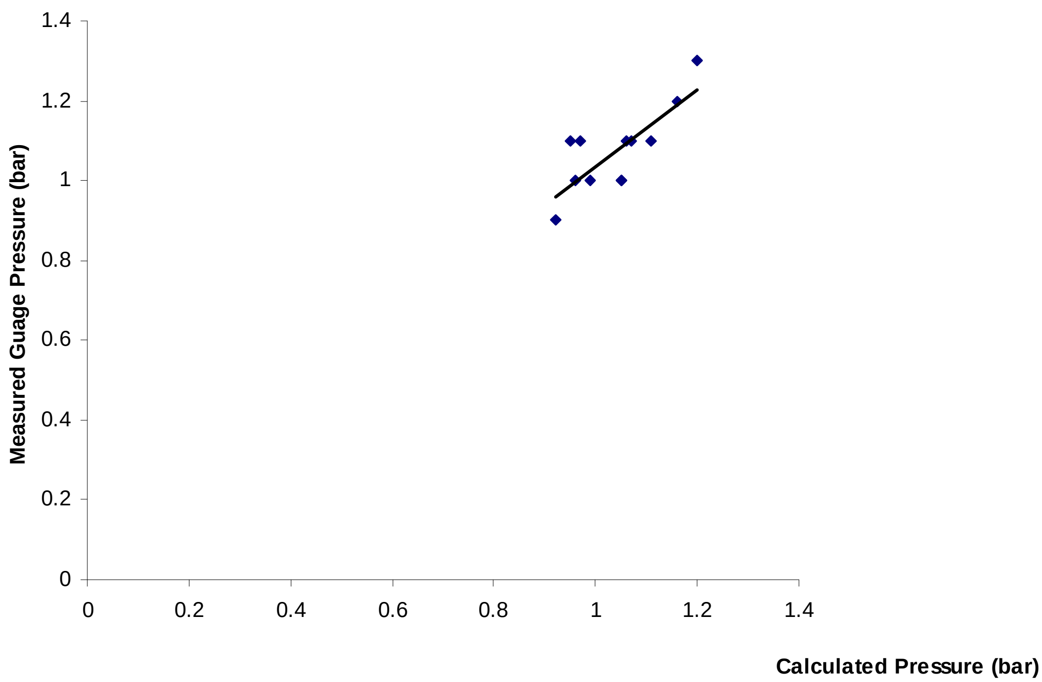

Figure 6: Plot of Measured Pressures Versus Calculated Pressures for First Distribution System

The calculated value of r is compared with values from statistical tables (Lipson and Seth, 1973) to test its significance. With degrees of freedom ν = n -2 = 10 where n is the number of data points (equal to 12) and 2 is the number of variables (x and y), the value of r is 0.708 for a 99% confidence level, from statistical tables (Lipson and Seth, 1973). Since 0.723 >0.708 there is 99% confidence that variations in the measured and calculated pressures are interdependent; and that 52.3% of the total variation of one type of pressure can be accounted for by the variation of the other.

ANALYSIS OF SECOND DISTRIBUTION SYSTEM

The second distribution system of Figures7 to 9 is analysed in like manner as the first case. For the second case, Table 4 gives the analysis of head losses and remaining heads at selected points in the distribution system; while Table 5 gives the calculated and measured pressures, together with the parameters for computing the correlation coefficient r. The corresponding scatter plot of Figure 10 between the calculated and measured pressures also shows a positive correlation, as for the first case.

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Utilizing Equation 7 and substituting values from Table 5 for this case,

$$r = \frac{0.1074}{\sqrt{0.1334 \times 0.1210}} = 0.845 = 84.5\%$$

$$r^2 = 0.715 = 71.5\%$$

In this case ν = n – 2 = 8 as n (the number of data points) is 10 and the number of variables is 2. From statistical tables (Lipson and Seth, 1973), for ν = 8 and 99% confidence level, the correlation coefficient is 0.765. As 0.845 > 0.765, there is 99% confidence of the interdependence of the measured and calculated pressures and 71.5% of the total variation of the measured or calculated pressure can be accounted for by the variation of the other.

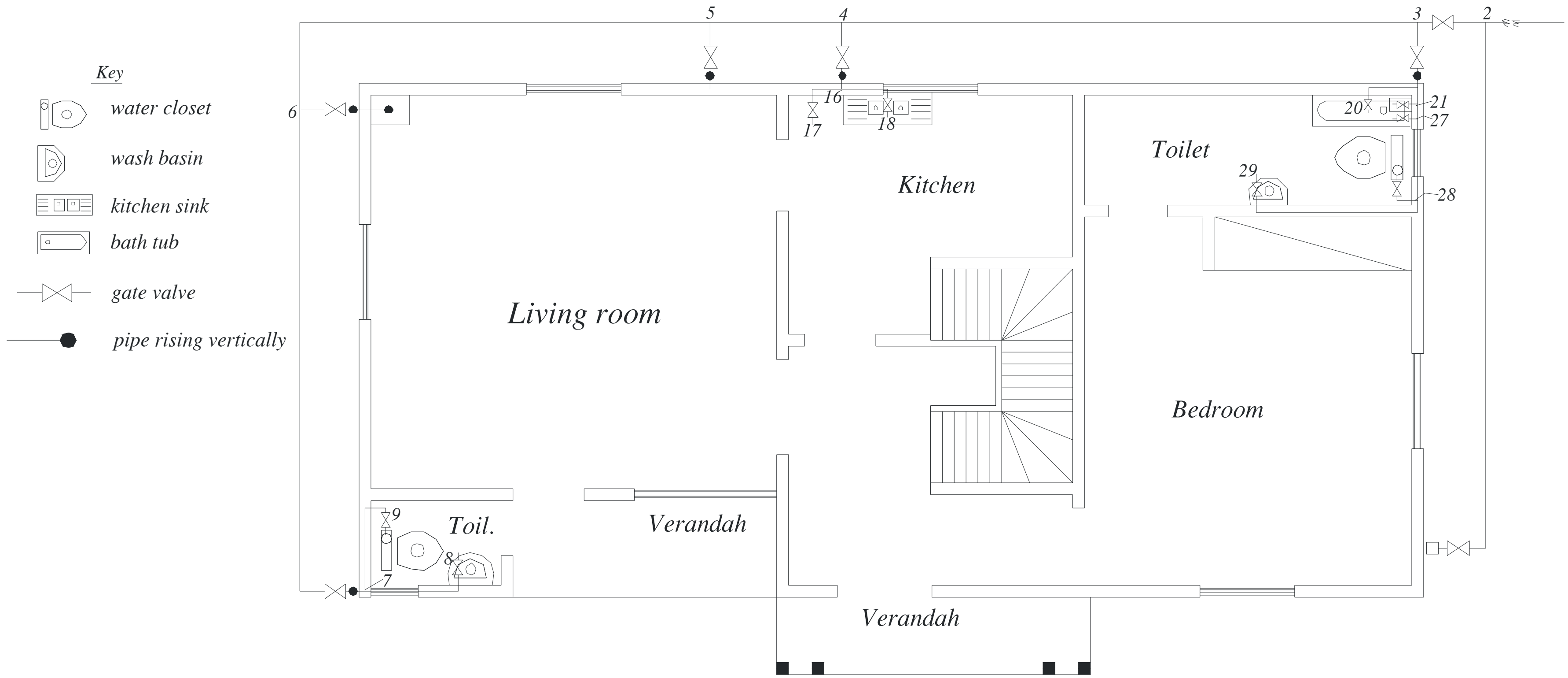

Figure 7: Ground Floor Plan of Second Distribution System

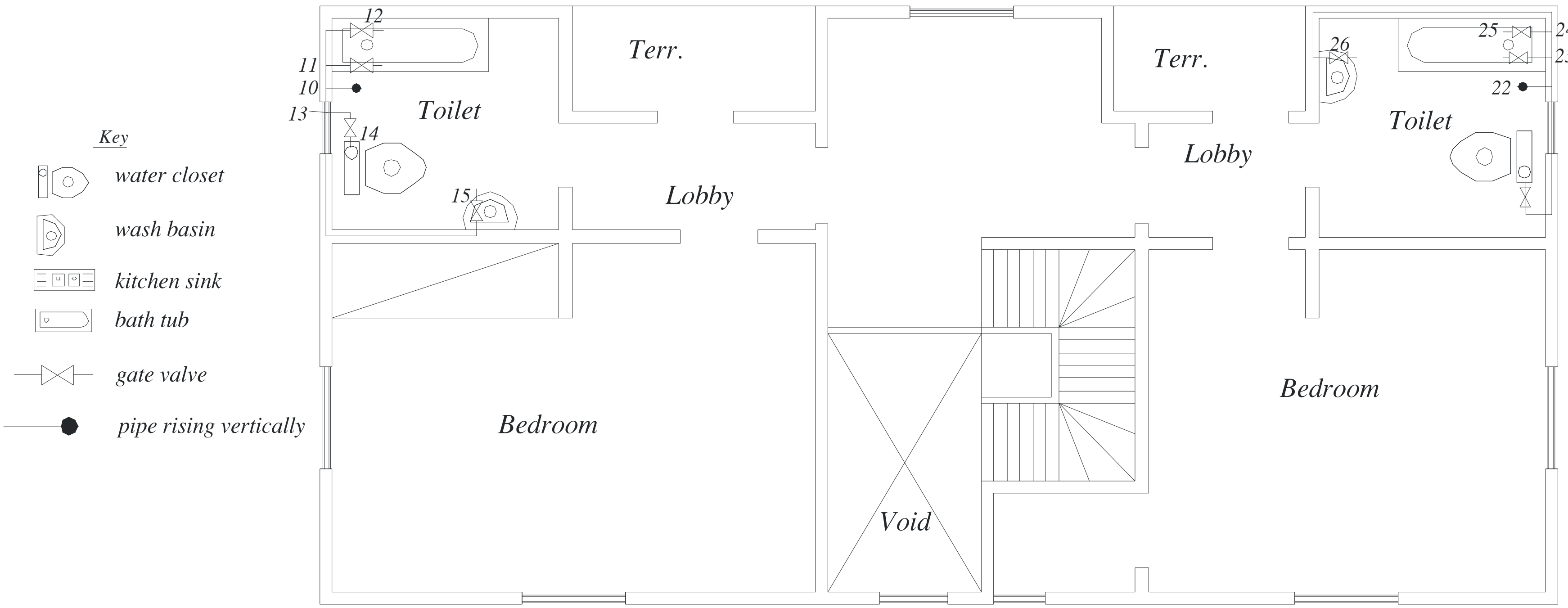

Figure 8: First Floor Plan of Second Distribution System

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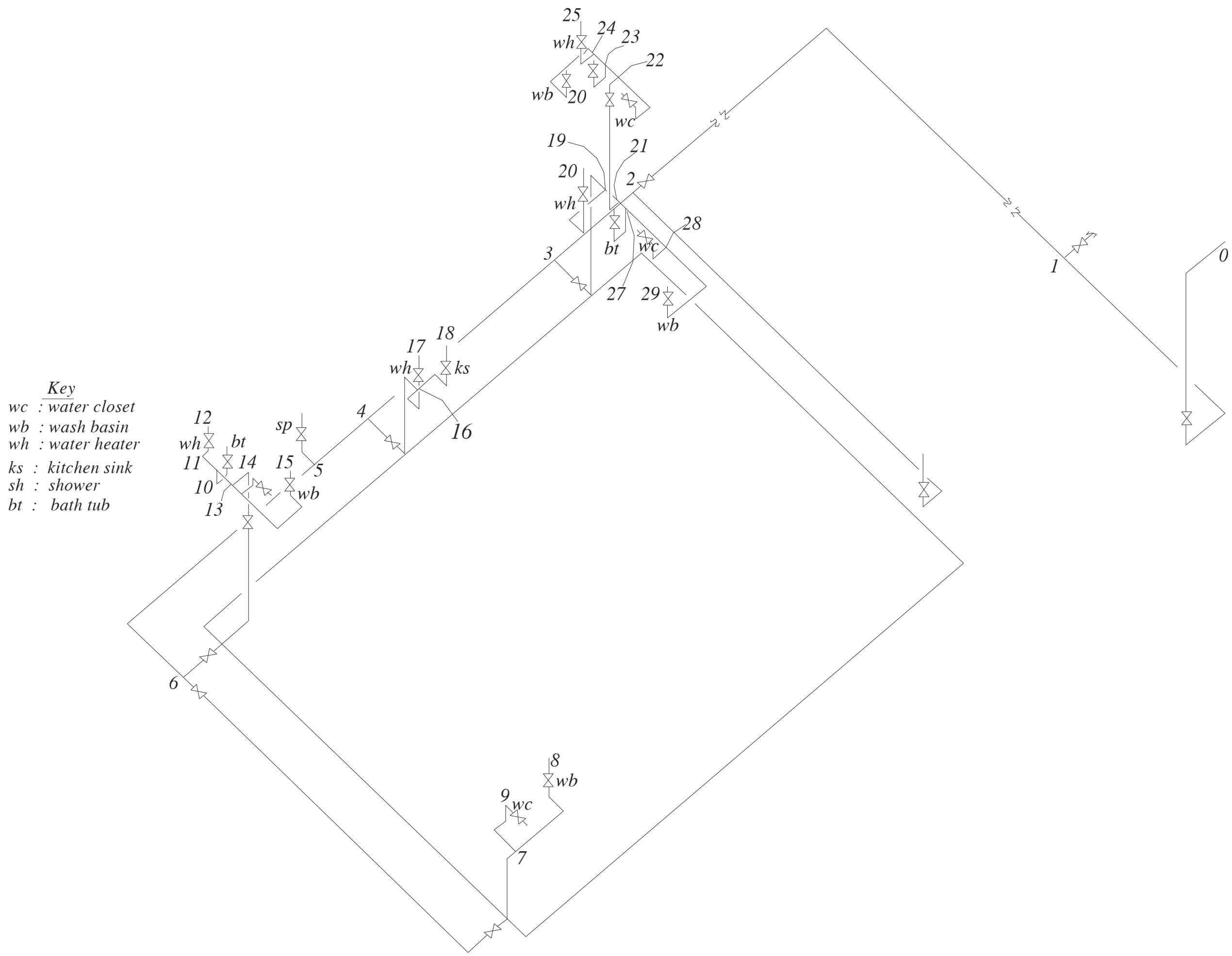

Figure 9: Isometric Sketch of Second Distribution System

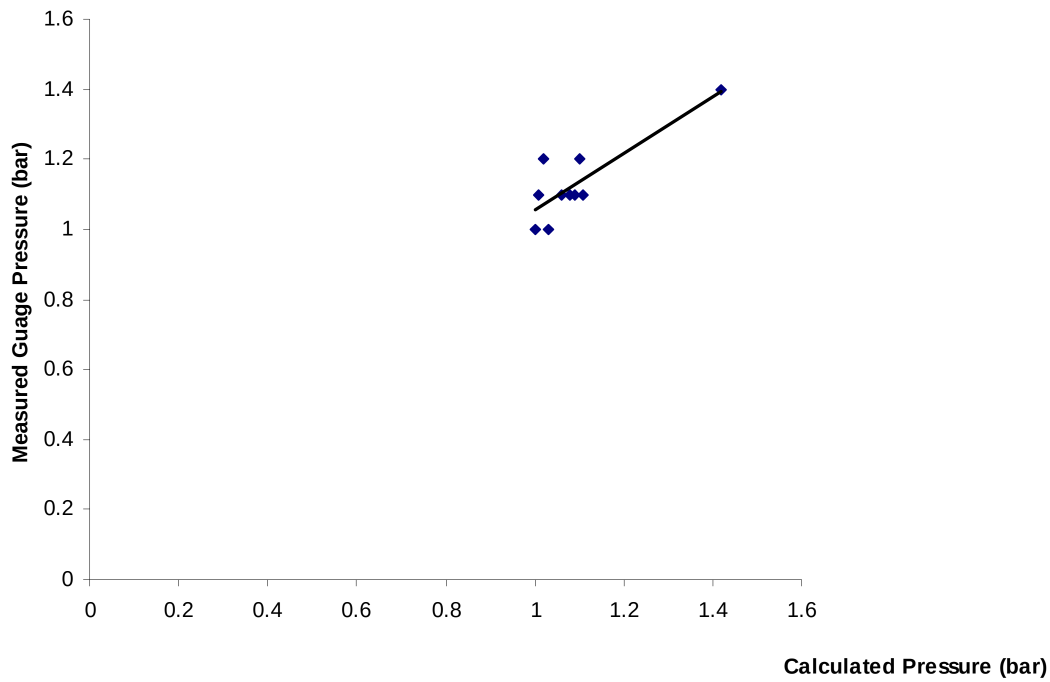

Figure 10: Plot of Measured Pressures Versus Calculated Pressures for Second Distribution System

Table 4: Summary of Pipe Sizing, Head Loss and Remaining Head Calculations, and Guage Readings for Second Distribution System

1	2	3	4	5	6	7	8	9	10	11	12		13
Pipe Section No.	Loading Units	Design Flow rate (L/s)	Measured Pipe Length (m)	Diameter (mm)	Actual H/L Value	Frictional Head Loss (m)	Types and Nos. of Fittings and Valves (Other than Reducers)	Reducers (mm x mm)	Head Loss due to Fittings and Valves (m)	Total Head Loss (m)	Remaining Head at Test point (m)		Pressure Gauge Reading at Test Point (bar)
											(m)	(bar)	
0-1	68.0	1.00	20.0	40	0.027	0.540	2 elbows, 1g.v., 1 tee	-	0.132	0.672	14.43	1.42	1.4
1-2	64.0	0.95	105.0	40	0.024	0.520	1 elbows, 1g.v., 1 tee	-	0.087	0.607	11.82	1.16	-
2-3	60.0	0.93	1.5	32	0.050	0.075	1 tee	40 x 32	0.145	0.022	11.60	1.14	-
3-4	29.0	0.58	7.3	32	0.027	0.197	1 tee	-	0.053	0.025	11.35	1.11	-
4-5	23.0	0.50	1.3	32	0.020	0.026	1 tee	-	0.039	0.065	11.29	1.11	1.1
5-6	19.0	0.45	9.7	25	0.050	0.485	1 elbows, 1 tee	32 x 25	0.123	0.608	10.68	1.05	-
6-7	3.5	0.12	8.6	20	0.015	0.129	3 elbows, 2g.v., 1 tee	25 x 20	0.036	0.165	10.51	1.03	1.0
7-8	1.5	0.05	1.5	15	0.019	0.029	2 elbows, 1g.v.	20 x 15	0.008	0.037	10.48	1.03	-
7-9	2.0	0.07	1.5	15	0.045	0.068	3 elbows, 1g.v.	20 x 15	0.021	0.089	10.42	1.02	1.2
6-10	15.5	0.41	4.5	25	0.043	0.194	2 elbows, 1g.v., 1 tee	-	0.133	0.327	10.35	1.02	-
10-13	3.5	0.12	0.5	20	0.015	0.008	1 tee	25 x 20	0.015	0.023	10.31	1.01	-
13-14	2.0	0.07	1.5	15	0.045	0.068	2 elbows, 1g.v.	20 x 15	0.015	0.083	10.22	1.00	-
13-15	1.5	0.05	2.5	15	0.019	0.048	3 elbows, 1g.v.	20 x 15	0.011	0.059	10.25	1.01	1.2
10-11	12.0	0.36	0.5	25	0.033	0.017	1 tee	-	0.055	0.072	10.28	1.01	-
11-12	2.0	0.07	2.5	15	0.045	0.113	2 elbows, 1g.v.	25 x 15	0.011	0.124	10.15	1.00	1.0
4-16	6.0	0.20	3.3	20	0.050	0.165	2 elbows, 1g.v., 1 tee	32 x 20	0.083	0.248	11.10	1.09	-
16-17	2.0	0.07	0.5	15	0.045	0.023	2 elbows, 1g.v.	20 x 15	0.010	0.033	11.07	1.09	-
16-18	4.0	0.14	0.5	20	0.030	0.015	2 elbows, 1g.v.	-	0.018	0.033	11.07	1.09	1.1
3-19	31.0	0.60	3.5	32	0.027	0.095	2 elbows, 1g.v., 1 tee	-	0.106	0.201	11.40	1.12	-
19-20	2.0	0.07	3.0	15	0.045	0.135	2 elbows, 1g.v.	32 x 15	0.011	0.146	11.25	1.10	-
19-21	29.0	0.58	0.5	32	0.027	0.014	1 tee	-	0.053	0.067	11.33	1.11	-
21-27	13.5	0.37	0.5	25	0.035	0.018	1 tee	32 x 25	0.061	0.079	11.25	1.10	1.0
27-28	3.5	0.12	1.3	20	0.015	0.020	1 tee	25 x 20	0.016	0.036	11.22	1.10	-
28-29	1.5	0.05	3.3	15	0.017	0.056	2 elbows, 1g.v.	20 x 15	0.008	0.064	11.15	1.09	-
21-22	15.5	0.41	3.5	25	0.043	0.151	2 elbows, 1g.v., 1 tee	32 x 25	0.137	0.288	11.04	1.08	1.1
22-23	13.5	0.37	0.5	25	0.035	0.018	1 tee	-	0.058	0.076	10.97	1.08	-
23-24	3.5	0.12	1.0	20	0.015	0.051	1 tee	25 x 20	0.016	0.031	10.90	1.07	-
24-25	2.0	0.07	2.5	15	0.045	0.113	1 elbows, 1g.v.	20 x15	0.009	0.122	10.81	1.06	1.1
24-26	1.5	0.05	3.0	15	0.017	0.051	3 elbows, 1g.v., 1 tee	20 x 15	0.011	0.062	10.88	1.07	-

Table 5: Parameters for Computing the Correlation Coefficient between Calculated and Measured Pressures for Second Distribution System

Test Point(in Figure 13)	Calculated Pressure at Test Point(bar) (xi)	Measured Gauge Pressure at Test Point (bar) (yi)	$x_i - \bar{x}$ (bar)	$y_i - \bar{y}$ (bar)	$(x_i - \bar{x})(y_i - \bar{y})$ (bar^2)	$(x_i - \bar{x})^2$ (bar^2)	$(y_i - \bar{y})^2$ (bar^2)
1	1.42	1.4	0.33	0.27	0.0891	0.0891	0.0729
5	1.11	1.1	0.02	- 0.03	- 0.0006	0.0004	0.0009
7	1.03	1.0	-0.06	- 0.13	0.0078	0.0036	0.0169
9	1.02	1.2	-0.07	0.07	- 0.0049	0.0049	0.0049
12	1.00	1.0	-0.09	- 0.13	0.0117	0.0081	0.0169
15	1.01	1.1	-0.08	- 0.03	0.0024	0.0064	0.0009
18	1.09	1.1	0.00	- 0.03	0.0000	0.0000	0.0009
22	1.08	1.1	-0.01	- 0.03	0.0003	0.0001	0.0009
25	1.06	1.1	-0.03	- 0.03	0.0009	0.0009	0.0009
27	1.10	1.2	0.01	0.07	0.0007	0.0001	0.0049
	$\sum = 10.92$	$\sum = 11.3$			$\sum = 0.1074$	$\sum = 0.1334$	$\sum = 0.1210$
	$\bar{x} = 1.09$	$\bar{y} = 1.13$					

DISCUSSION OF RESULTS

Given inevitable sources of experimental error, there are generally higher measured pressure heads than the calculated values, as observed from the mean values in Tables 3 and 5. This might be due to the adopted calculation method which has slightly over-estimated values of total head loss, resulting in lower calculated pressures at the test points. However, the ranges of values of calculated and measured heads are quite close.

It is more useful to over-estimate the head losses, than to under-estimate them, as this provides some margin of safety in distribution system design. The two studied cases thus give credence to the calculation methods.

Possible sources of experimental error include instrument (pressure guage) errors; and operator’s errors in the measurement of pressures, pipe lengths and permissible head loss values (from the pipe sizing graph of Figure5). Also, in many cases, while the calculated pressures are taken at pipe nodes (i.e. tees) and outlets, the pressure guage readings are taken conveniently close to those nodes and outlets, at valves and union connectors. There is, thereby, some ‘location’ error introduced in the analyses, but this was minimized as much as possible.

CONCLUSION

As the measured pressures are close to the calculated values, the adopted methods of pipe sizing and head loss calculation are applicable in building water distribution system design. Also, the calculation method slightly over-estimates the pressure losses in the system; hence, providing some margin of safety in system designs.

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