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Validation of Regression Models for the Fraction of Fitting Loss in Index Pipe Runs (Part 1: Water Distribution within Buildings)

J. I. Sodiki[1], E. M. Adigio[2]
[1]Department of Mechanical Engineering, Rivers State University, P.M.B. 5080, Port Harcourt, Nigeria
[2]Department of Mechanical and Marine Engineering, Niger Delta University, Wilberforce Island, Bayelsa State, Nigeria
([1]jisodiki_partners@yahoo.com, [2]emadigio@yahoo.com)

Abstract- In order to approximate the total loss through index pipe runs in water distribution systems, several percentages of the frictional loss (which show no clear statistical basis) had been proposed. However, recent studies by the authors have arrived at regression equations which relate the fraction of the total head loss due to pipe fittings with distribution system parameters within buildings, such as length of first index pipe run, reservoir discharge and number of sanitary appliances supplied. The present study validates these equations by comparison with results of case studies of existing water distribution systems within buildings. All the results of the regression equations gave variances less than 20% of the case study results. The regression equations are, thus, useful for approximating the fractions of total head loss due to pipe fittings in water distribution index pipe runs, within the limits of values of system parameters utilized in obtaining the regression equations.

Keywords- *Validation of Regression Equations, Loss through Pipe Fittings, Water Distribution within Buildings*

I. INTRODUCTION

In gravity flow water distribution systems, the available pressure at any point is progressively reduced downstream of the elevated storage; due to frictional losses and losses through pipe fittings (such as elbows, tees, reducers and values), respectively referred to as major and minor losses.

Consequently, extensive pipe runs result in increased total friction loss while a multiplicity of fittings is associated with increased total fitting loss. However, the number and type of each fitting in a given pipe run are usually specified such as to achieve proper functioning of the distribution system; and it can be reasonably assumed that, for a given index pipe run, the ratio between the total frictional loss and the total fitting loss may vary with varying length of run, flow rate and other system parameters.

For facilitating the estimation of pressure losses in index pipe runs, the determination of this ratio is useful in many practical cases. The dependence of the ratio on length of pipe run and other parameters is exemplified by the stipulation of Spirax Sarco Ltd [1] of 10% of the friction loss for most purposes, but 30% for short pipes having a lot of fittings, to account for the total loss through fittings in index runs.

Several other studies have also resulted in various fractions (or percentages) that approximate the fittings loss component for index pipe runs. In this regard, in order to account for the head loss through all installed pipe fittings in the procedure of selecting hot water circulating pumps, Church [2] had suggested a 150% multiplication of the measured length of the longest (i.e. first index) pipe run to calculate the frictional loss. This represents 50% of the frictional loss that account for that due to all installed fittings in the first index run.

In the same vein, in considering water distribution systems in buildings, Barry [3] had considered it necessary to make an estimate of the likely length of pipe whose resistance to flow is equivalent to the resistance of the pipe fittings, which should be taken as a percentage of the actual pipe length. In his opinion, this percentage might vary from 25 to over 100, which with experience would approach a fair degree of accuracy. Also, in analyzing head losses in water distribution systems, Tiscala U.K. Ltd [4] had suggested that when making approximate calculations, 10%, 15%, 20% or more may be added to the pressure loss in straight pipe runs to account for the loss through all installed pipe fittings. Also, the Virginia Department of Housing and Community Development [5] in their Plumbing Code stipulate that 50% of the index pipe length should be added to account for losses in fittings and valves; while Uponor Plumbing Systems [6] recommend between 20% and 30%.

Also, Apsley [7] had stated “minor losses are one-off losses occurring at single points and, in the grand scheme of things, frictional losses dominate. For long pipelines minor losses are often ignored”. This statement implies that for long pipelines, the loss percentage due to fittings should be taken as 0%.

Furthermore, Boman and Shukla [8] had observed on micro-irrigation systems that losses through fittings and valves might be aggregated to a friction loss safety factor and that 10% be used. The Saskatchewan Ministry of Agriculture [9] also maintains this 10% for irrigation pipework design as they stated “minor losses in the manifold, submain, mainline and suction pipe, due to connectors, valves and fittings are estimated as 10% of the total loss when determining total dynamic head and pump size”.

Hence, by applying the foregoing percentages (or ratios) the total head loss in a given index pipe run can quickly be estimated by adding to the total frictional loss, the frictional loss component being normally easier to calculate than the total fitting loss.

However, all the foregoing approximations for estimating the fitting loss component show no clear statistical basis. In particular, investigations have further shown no recorded previous study by others which pertain to the variation of the frictional and fitting loss components with varying system complexity. These knowledge gaps have been addressed in recent studies by the authors [10, 11, 12, 13, 14].

II. Study Approach

Utilizing commonly occurring water distribution configurations in buildings, the Hazen-Williams equation [15]

$$S = \frac{h_f}{l} = \frac{10.67 q^{1.85}}{C^{1.85} d^{4.87}} \tag{1}$$

where S= frictional head loss per unit length of pipe (h_f/l)

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

c = Hazen-Williams roughness coefficient of the internal pipe wall

and d = pipe diameter (in m),

in its graphical form of Fig. 1 [16] is used to generate data on frictional head loss, the graphical form being practically more direct in application than the equation. The head loss values h_p through pipe fittings commonly installed in water distribution systems are generated using the head loss coefficient k [15] of the particular fitting type, as input to the D'Arcy-Weisbach type equation

$$h_p = k \cdot \frac{v^2}{2g} \tag{2}$$

where v = flow velocity (in m/s) and g = gravitational acceleration (in m/s^2).

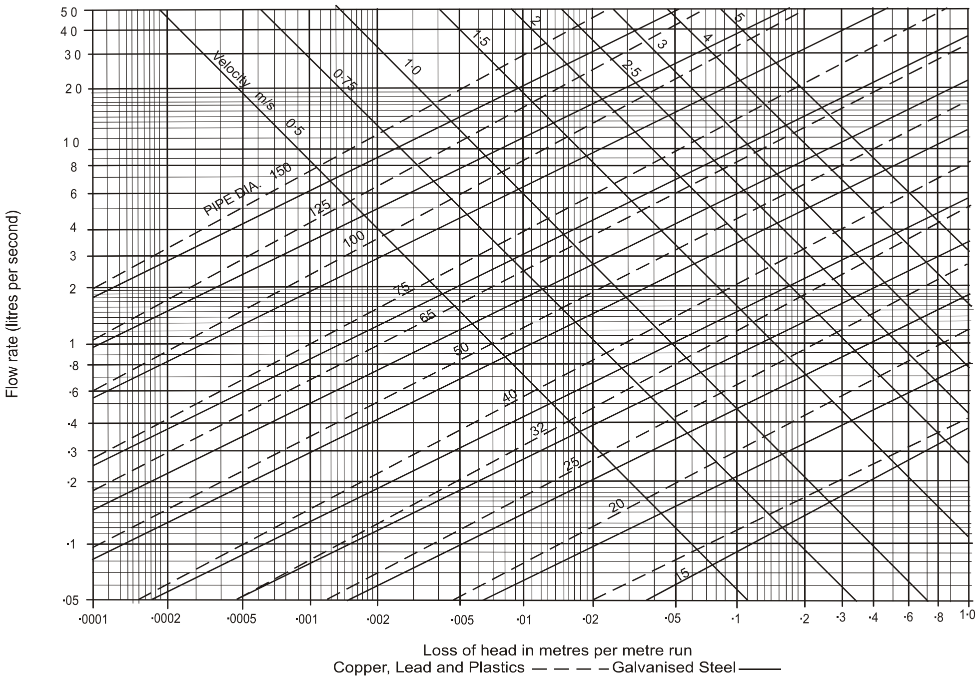

Figure 1. Pipe Sizing Graph [16]

Expressing velocity in terms of d and q and putting g= 9.81m/s^2, Eqn. 2 becomes:

$$h_p = 0.08256 k d^{-4} q^2 \tag{3}$$

As Eqns. 1 and 3 apply to each pipe section along an index pipe run having several branches, their additive forms should be applied along the index run. Theoretically, the total loss for a composite index pipe run is, thus,

$$H = h_f + h_p = \frac{10.67}{C^{1.85}} \sum_{j=1}^{n} l_j d_j^{-4.867} q_j^{1.85} + 0.08256 \sum_{j=1}^{n} d_j^{-4} q_j^{2} \left(\sum_{i=1}^{m} k_{ij} \right) \tag{4}$$

where i denotes the i^{th} pipe fitting in a given pipe section, m is the number of fittings in a given section, j denotes the j^{th} pipe section, while n is the number of pipe sections in the index run.

In the study, the plastic pipe material is chosen as it presently constitutes the most widely used material in water distribution systems. Plastic water pipe materials include polybutylene, unplasticized polyvinylchloride (UPVC), chlorinated polyvinylchloride (UPVC), polyethylene (PE), etc. All of these plastics are categorized as smooth in terms of frictional resistance [16, 17, 18]. Also, other pipe materials which can be categorized as smooth (such as copper and brass) are covered in the study, since the concern is the pressure loss in water distribution systems. However, similar studies may also be carried out for distribution systems utilizing other pipe materials.

The variation of the frictional and fitting loss components (and hence the ratio or percentage of the fitting loss component needed for approximation purposes) is studied by varying the complexity of the distribution systems. In one such configuration (Fig. 2), water is distributed to a range of toilet rooms in a hotel block. Each room contains a water closet, wash basin, bath tub and a water heater. This pipework arrangement represents a commonly occurring scenario in hotel blocks.

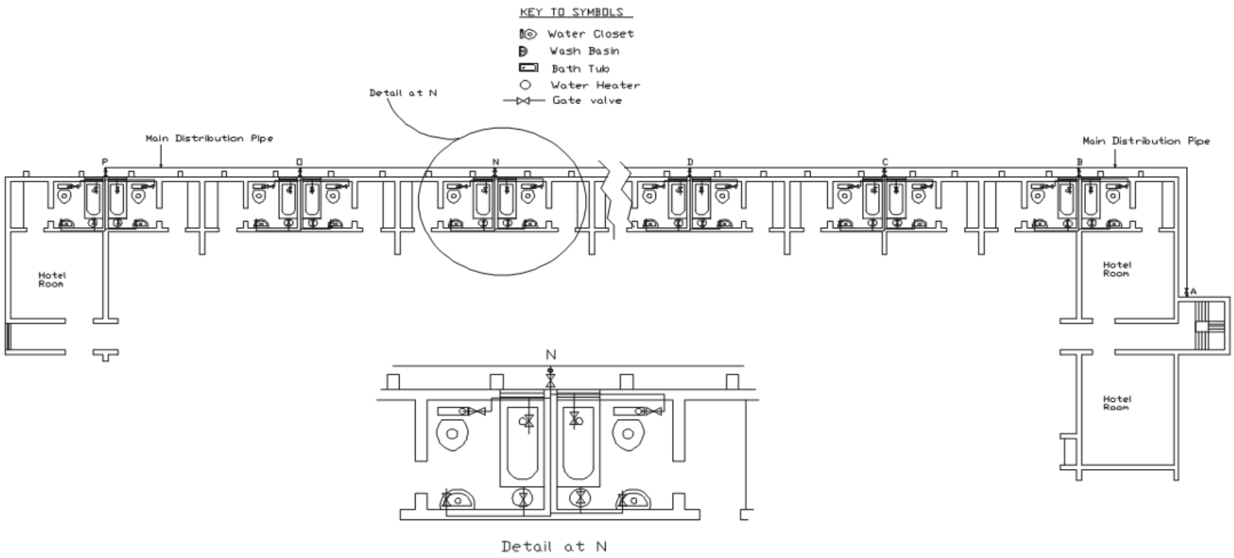

Figure 2. Water Distribution Layout to a Range of Toilets in a Hotel Building

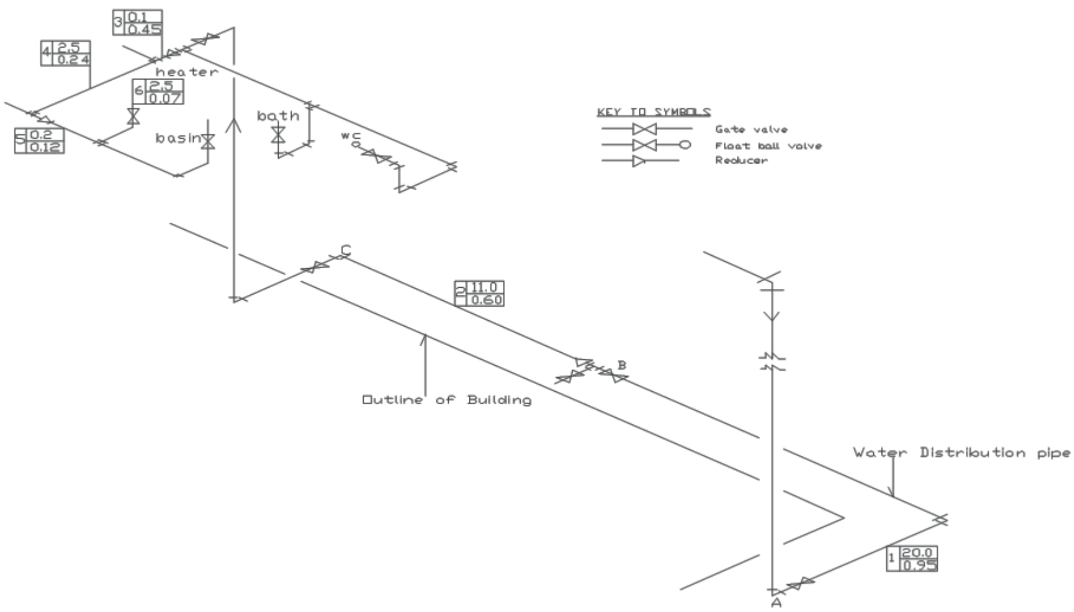

Figure 3. Isometric Sketch of Distribution System for 36.3m First Index Run, 16 Appliances and 0.95 l/s Flow Rate

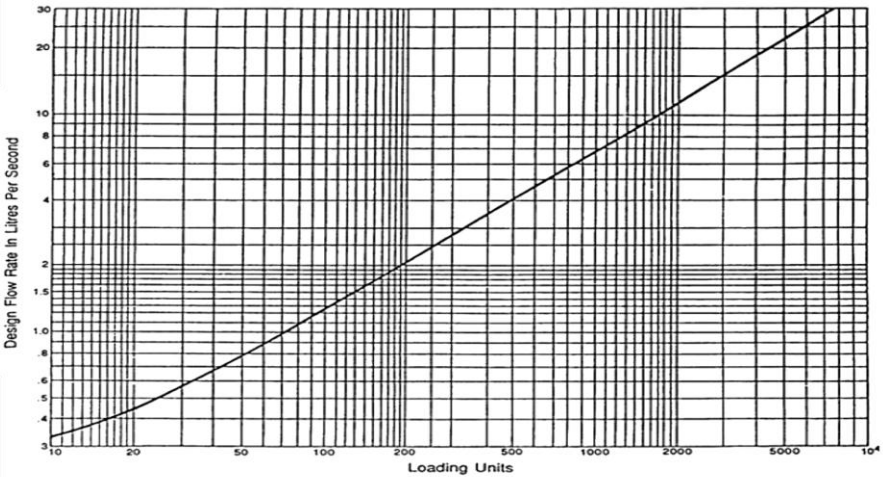

Figure 4. Graph of Loading Unit versus Flow Rate [16]

In the analysis of the head losses in the first index pipe run of Fig. 2, the pipe run from A and B and up to the farthest fixture supplied by the branch from B is first considered (with the extension on the main distribution pipe from point B towards C being considered as non – existent).

Next, the analysis is repeated for the pipe run from A to C and up to the farthest sanitary appliance supplied by the branch from C (again considering the extension on the main distribution pipe from point C towards D as non-existent). Subsequent steps in the analysis are carried out for extended first index pipe runs and the progressive increase in length of first index run provides the variation of the complexity of pipework in terms of length of index run, total flow rate from the reservoir, and number of appliances supplied from the reservoir. For a given available head at the initial point A, the head loss components due to friction and pipe fittings are calculated for each independent first index pipe run.

The graphical method adopted for pipe sizing and estimation of head losses is illustrated using the pipe run from A to C and up to the farthest fixture supplied by the branch from C. This pipe run is shown as an isometric sketch in Fig. 3 in which the pipe sections are labeled using boxes. The number to the left of the box is the pipe section number, the number to the top right is the measured pipe length (in m), and that on the bottom right is the flow rate in the pipe section (in l/s).

In the computations, loading units, which account for the non-simultaneous use of all the installed appliances, are assigned to the appliances [16]. The units are 2 for a water closet cistern, 1.5 for a wash basin, 10 for a bath tub and 2 for a water heater cylinder. Hence, cumulative units for each pipe section are obtained and used to determine the flow rates from the graph of Fig. 4. For loading units below 10 which are not presented in Fig. 4, linear extrapolations are made to obtain corresponding flow rates.

Now, for a reservoir height above point A of 10m and a height of the water heater in pipe section 6 (which is the final section of this index run) above point A of 2.5m, the pressure head H available in the first index run = 10m - 2.5m = 7.5m. The measured length of the index run is L = 36.3m. Then, the rate of head loss per metre run (H/L) should not exceed 7.5/36.3 = 0.207m/m run.

Applying this calculated head loss per metre run to each flow rate, the pipe sizes are determined using the graph of Fig. 1. For instance, for pipe section 2 which has a cumulative unit of 31.0 with a corresponding flow rate of 0.6l/s, a 25mm pipe is selected from Fig. 1. The actual values of H/L are obtained at the intersection of the lines of flow rate and pipe diameter. For pipe section 2, as an example, the actual H/L value is 0.085m/m run and the measured pipe length is 11.0m.

Thus, the head loss due to friction for this pipe section is 0.085 x 11.0m = 0.935m. Table 1 shows the pipe sizing estimates and the calculated head losses for the index run from the reservoir to pipe section 6.

With the pipe sizes (diameters) entered in Column 6, locations of reducers in the first index run are determined. Other types of fitting (i.e. elbows, tees and valves) in the first index run are specified in consideration of system functionality. In pipe section 6, for instance, there is one elbow and one gate valve; and for $d = 0.015m$ and $q = 0.07 \times 10^{-3}$ m^3/s, the loss through fittings using Eqn. 3, is

$$h_p = (0.75 + 0.25) \times 0.08256 \times 0.015^{-4} \times (0.07 \times 10^{-3})^2 = 0.008\text{m}$$

Similarly, in pipe section 5, there is one 20mm x 15mm reducer (which has d_1/d_2= 1.33) and one tee. k for the reducer is obtained from Table 2 as 0.139 and k for the tee, as specified by Giles et al [15] is 2. Then, from Eqn. 3,

$$h_p = (0.139 + 2) \times 0.08256 \times 0.015^{-4} \times (0.12 \times 10^{-3})^2 = 0.050\text{m}$$

Thus, for the different pipe sections and the different loading units, and hence flow rates, pipe lengths and permissible maximum H/L value (Columns 1, 2, 3, 4 and 5, respectively) different pipe diameters, frictional loss h_f and loss through fittings h_p are obtained. From Table 1 the total frictional loss is 2.698m while the total fitting loss in 1.045m. Thus, the fitting loss fraction of the total is 0.279.

Table 3 summarizes the calculated total frictional and fitting losses, as well as the ratios of fitting loss to total loss for the varying complexities of pipework for the distribution layout of Fig. 2. Values in Tables 3 were subsequently utilized for a regression analysis. The flow chart of Fig. 5 further illustrates the study procedure up to the regression analysis and validation of the regression model equations.

TABLE I. PARAMETERS OF DISTRIBUTION SYSTEM FOR 36.3M FIRST INDEX RUN, 16 APPLIANCES, 0.95L/S FLOW RATE

1	2	3	4	5	6	7	8	9	10	11
Pipe section no. (see Fig. 3)	Loading units	Design flow (l/s)	Pipe length(m)	Permissible maximum H/L	Dia. (mm)	Actual H/L	Frictional head loss, $h_f(m)$	Reducers (mm x mm)	Fittings (other than reducers)	Loss thru fittings, h_p (m)
1	62.0	0.95	20.0	0.207	32	0.070	1.400	-	3 elbows, 2 gate valves, 1 tee	0.338
2	31.0	0.60	11.0	0.207	25	0.085	0.935	32 x 25	3 elbows, 2 gate valves, 1 tee	0.370
3	19.0	0.45	0.1	0.207	20	0.20	0.020	25 x 20	1 tee	0.220
4	7.0	0.24	2.5	0.207	20	0.065	0.163	-	1 tee	0.059
5	3.5	0.12	0.2	0.207	15	0.150	0.030	20 x 15	1 tee	0.050
6	2.0	0.07	2.5	0.207	15	0.060	0.150	-	1 elbow, 1 gate valve	0.008
Total			36.3				2.698			1.045

TABLE II. VALUES OF K FOR REDUCERS [15]

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 III. RATIOS OF LOSS THROUGH FITTINGS TO TOTAL LOSS FOR VARYING PIPE WORK COMPLEXITIES (FOR DISTRIBUTION WITHIN BUILDINGS)

1	2	3	4	5	6	7
Length of 1st index pipe run (m)	Total flow rate through main distribution pipe (l/s)	No. of appliances served by main distribution pipe	Frictional loss in 1st index run (m)	Loss through fittings in 1st index run (m)	Total loss in 1st index run (m)	Ratio of loss through fittings to total loss
28.3	0.60	8	2.318	0.889	3.207	0.277
36.3	0.95	16	2.698	1.045	3.743	0.279
44.3	1.25	24	3.943	1.302	5.245	0.248
52.3	1.55	32	3.747	1.302	5.049	0.258
60.3	1.80	40	4.777	1.594	6.371	0.250
68.3	2.20	48	4.337	1.627	5.964	0.273
76.3	2.60	56	4.245	1.724	5.969	0.289
84.3	2.70	64	4.625	1.936	6.561	0.295
92.3	2.90	72	5.005	2.069	7.074	0.282
100.3	2.95	80	4.304	2.079	6.383	0.326
108.3	3.20	88	4.379	2.318	6.697	0.346
116.3	3.50	96	4.467	2.666	7.133	0.374
124.3	3.70	104	4.147	2.542	6.689	0.380
132.3	4.00	112	4.059	2.658	6.717	0.396
140.3	4.40	120	4.311	2.880	7.191	0.401

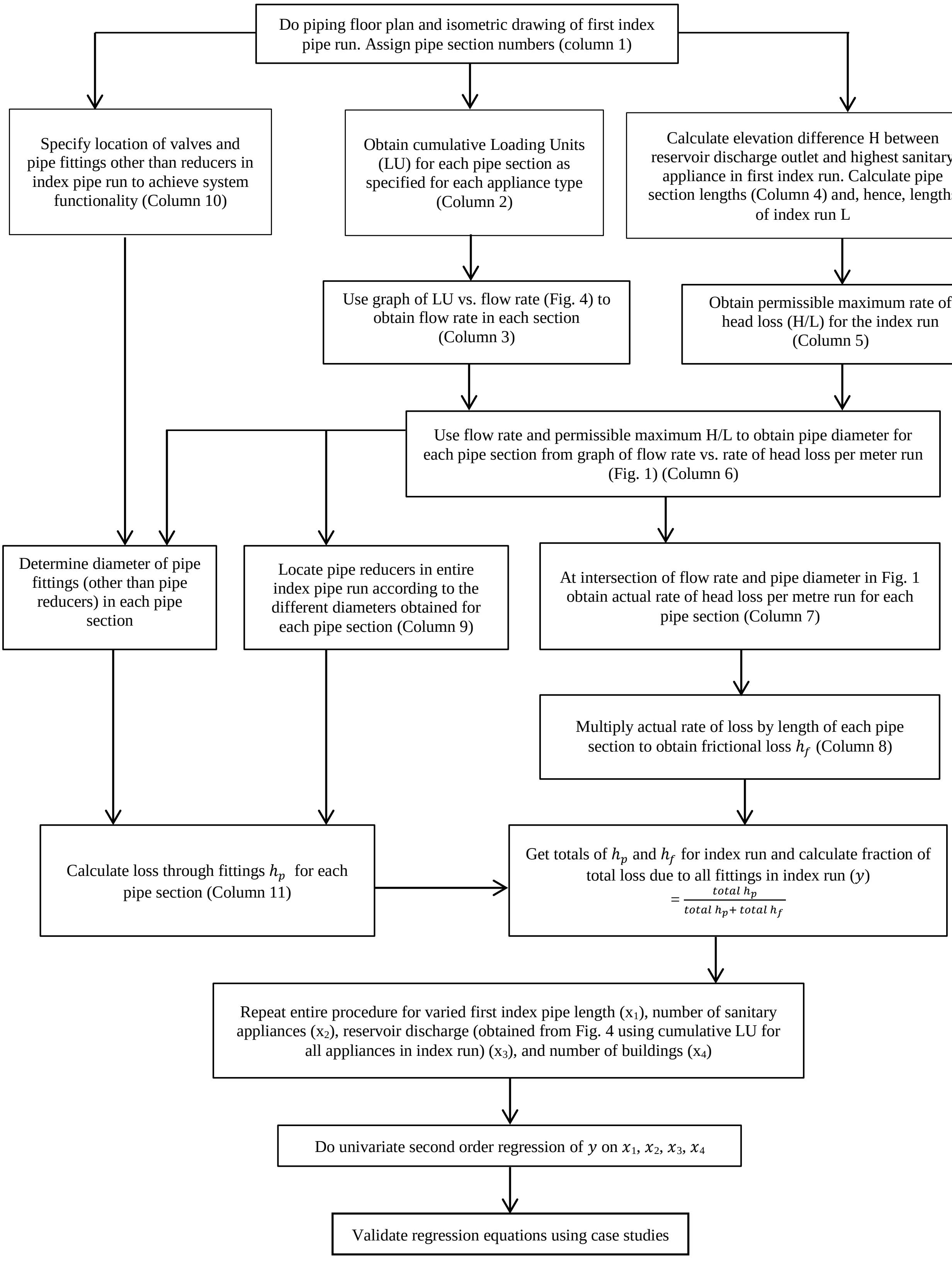

Figure 5. Flow Chart of Procedure for Calculating the Head Loss Fractions

III. REGRESSION ANALYSIS

Initial results of the study showed the second order polynomial as a better fit, for the variations of the ratio of the loss through fittings to the total loss for varying pipework complexities, than the linear and other graphical forms. This graphical form, therefore, suggests a second order regression analysis.

It is further observed that the measures of system complexity, namely length of first index pipe run, total water discharge from the reservoir, number of sanitary appliances supplied from the reservoir, and number of buildings supplied, are dependent on each other. Thus, the design water discharge in a distribution system depends on the number of sanitary appliances (and buildings) supplied; and the length of first index pipe run depends on the number of appliances and buildings supplied.

This dependence, therefore, necessitates the application of univariate second order regression analysis for the variation of the ratio of loss due to fittings to the total loss (which is the dependent variable) with each measure of system complexity (which is the independent variable).

The relevant variation equation is, thus [19]

$$y = a_0 + a_1 x + a_2 x^2 \quad (5)$$

where the dependent variable y is regressed on the independent variable x; and a_0, a_1 and a_2 are the regression parameters.

Using the values of independent and dependent variables presented in Table 3 in the Microsoft Office Excel graphical program, the regression equations and measures of correlation r^2 and r for the respective system parameters were generated as shown in table 4.

IV. VALIDATION OF REGRESSION MODEL EQUATIONS USING CASE STUDIES

Analyses of other cases of distribution systems within buildings are carried out using the same calculation procedures applied in obtaining the regression models. Comparisons are thereby made of the ratios of head loss due to fittings to the total head loss obtained from each case of distribution system with the results if the regression model equations.

Following from the suggestion by Keller and Bliesner [20] that a 20% addition be allowed to the estimated total loss as a safety margin, any variance not greater than 20% from the result of a case study of the corresponding regression model result is regarded as acceptable for approximation purposes. Three distribution systems within buildings are taken as case studies.

A. 448 – Bed Student Hostel

In this case study, water is distributed at a calculated reservoir discharge of $4.4 l/s$ and an available system pressure head of 4m. The building ground floor plan and the isometric drawing showing the water distribution system are, respectively, Figs. 7 and 8. The other floor plans are not shown in order to maintain brevity. Table 5 gives a summary of the calculations for pipe sizing and the head loss components.

It is found from Table 5 that the total frictional loss in the first index run is 1.103m while the total loss through pipe fittings is 0.808 m, resulting in a total of 1.911m and a fraction of loss through fittings of 0.423. The frictional loss fraction is, therefore, 0.577.

Now, applying the regression equation which relates the length of index pipe run to the fraction of loss due to fittings

$$y = 0.294 - 0.0012x_1 + 1.6 \times 10^{-5} x_1^2 \quad (6)$$

with a first index pipe length of 135.5m gives

$$y = 0.294 - 0.0012 \times 135.5 + 1.6 \times 10^{-5} \times 135.5^2 = 0.425$$

The value of 0.425 being at variance from 0.423 by only 0.5% validates the regression equation.

Further applying the derived regression model equation which relates the reservoir discharge to the fraction of loss due to fittings

$$y = 0.286 - 0.04x_2 + 0.016x_2^2 \quad (7)$$

we get

$$y = 0.286 - 0.04(4.4) + 0.016(4.4)^2 = 0.420$$

This regression result being at variance from 0.423 by only 7.0% further validates the regression equation.

Further applying the regression equation which relates the number of appliances to the fraction of loss due to fittings

$$y = 0.275 + 1 \times 10^{-4} x_3 + 2 \times 10^{-6} x_3^2 \quad (8)$$

with a total number of appliances of 270 results in

$$y = 0.275 + 1 \times 10^{-4} \times 270 + 2 \times 10^{-6} \times 270^2 = 0.448$$

This value, being at variance with the case study result of 0.423 by only 5.9%, validates the regression equation.

TABLE IV. RESULTS OF REGRESSION ANALYSIS FOR DISTRIBUTION WITHIN BUILDINGS

Independent Variable (system parameter)	Regression Equation for y, Fraction of Loss due to Pipe Fittings	r^2	r
Length of First Index Pipe, Run x_1 (m)	$y = 0.294 - 0.0012x + 1.6 \times 10^{-5} x_1^2$	0.937	0.968
Reservoir Discharge, x_2 (l/s)	$y = 0.286 - 0.04 x_2 + 0.016 x_2^2$	0.903	0.950
Number of Sanitary Appliances, x_3	$y = 0.275 + 1 \times 10^{-4} x_3 + 2 \times 10^{-6} x_3^2$	0.937	0.968

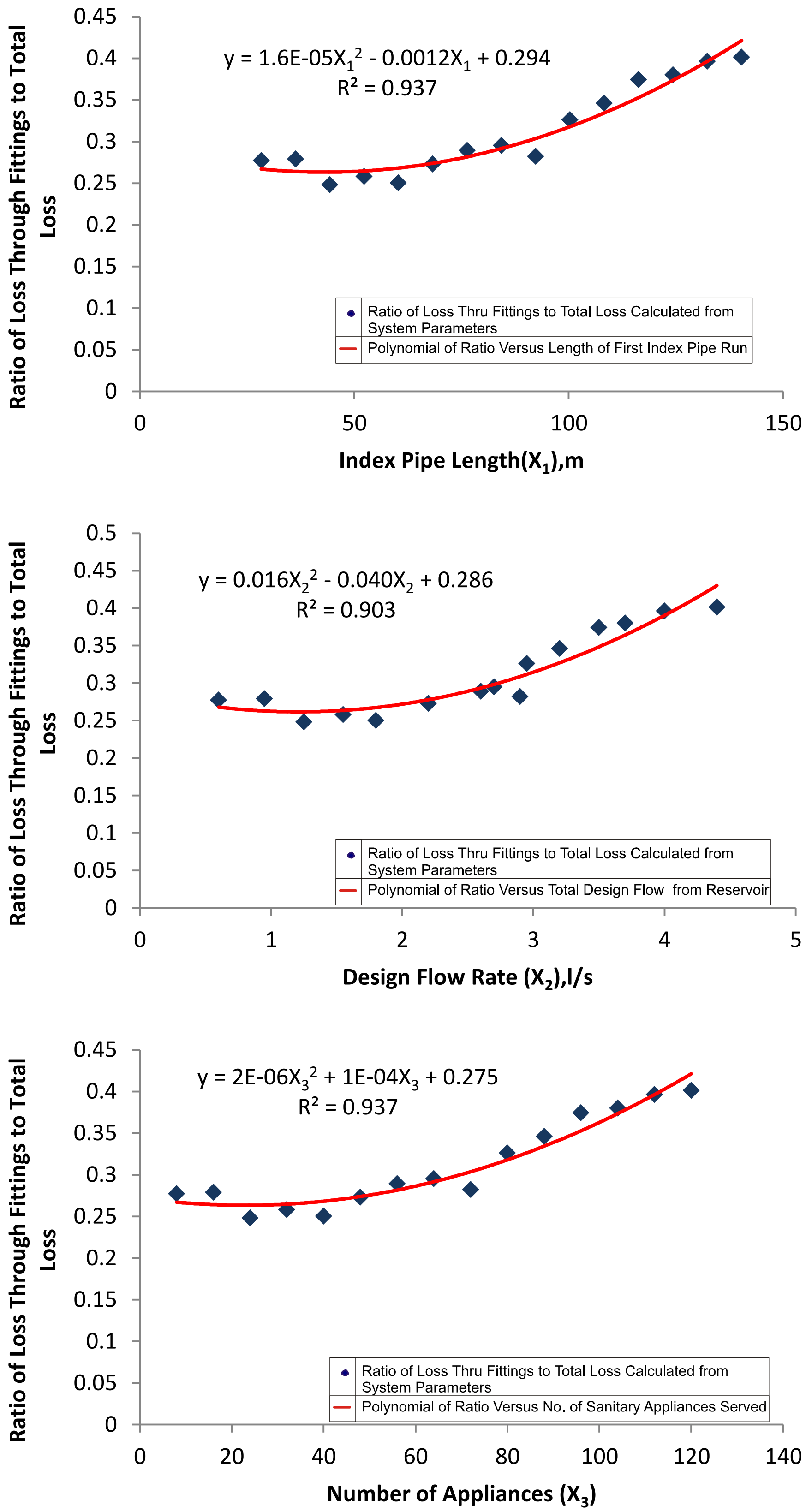

Figure 6. Variation of Ratio of Loss through Fittings to Total Head Loss with Pipework Complexity (for Distribution within Building)

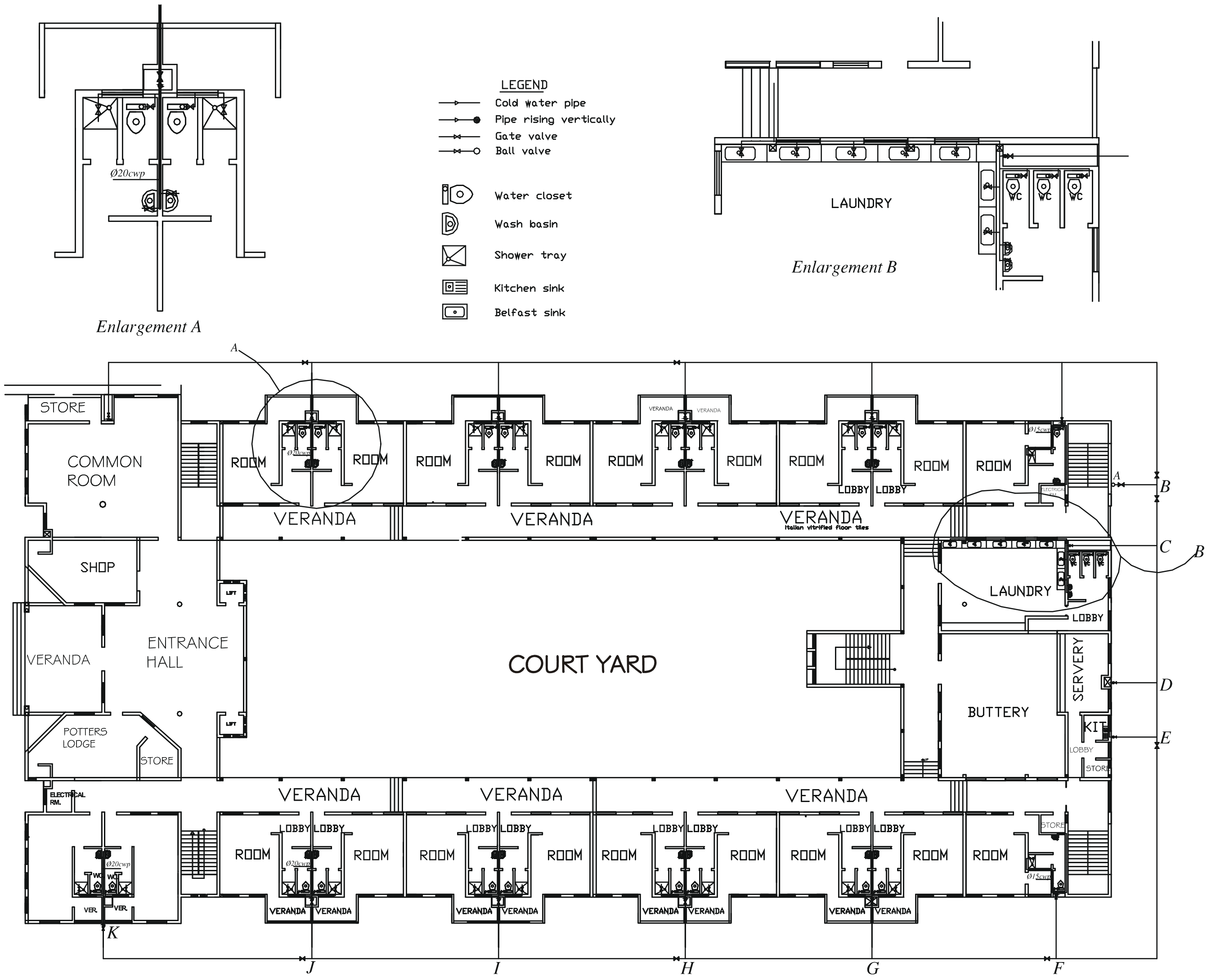

Figure 7. Ground Floor Plan of 448-Bed Student Hostel

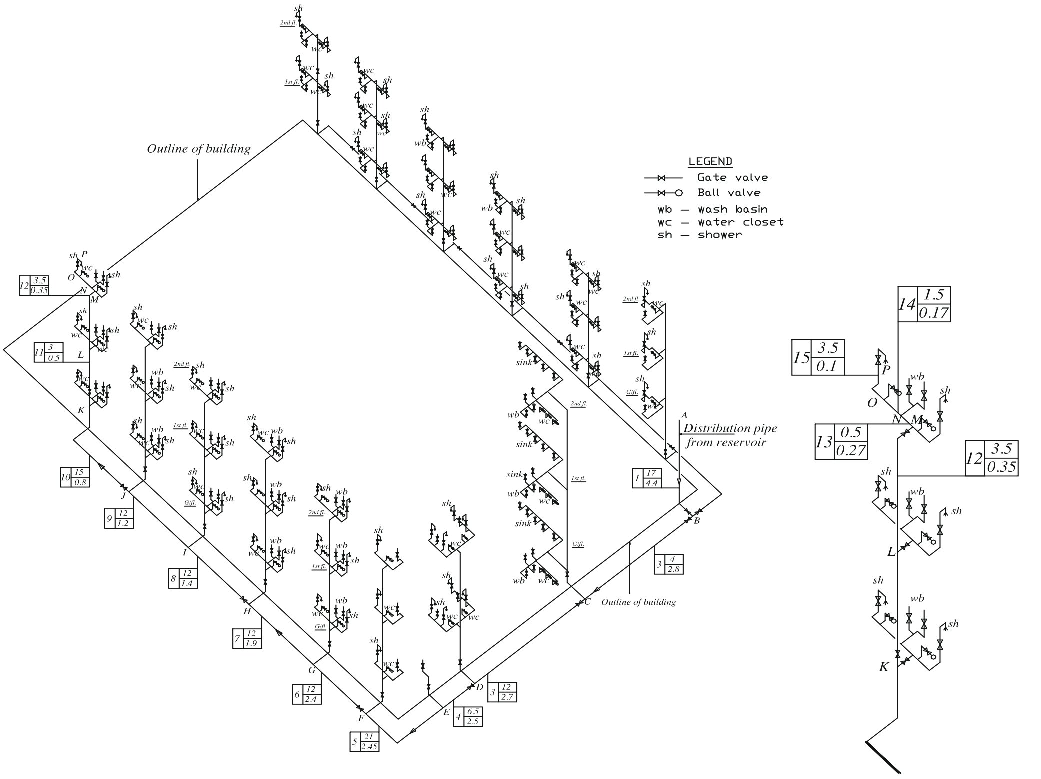

Figure 8. Isometric Sketch Showing Water Distribution of 448-Bed Student Hostel

TABLE V. PIPE SIZING AND CALCULATION OF HEAD LOSS COMPONENTS FOR DISTRIBUTION TO 448 – BED STUDENT HOSTEL

Pipe section no. (see Figs. 7 and 8)	Loadin g units	Design flow (l/s)	Pipe length (m)	Permissible $H/_L$	Diameter (mm)	Actual $H/_L$	Frictional head loss, h_f	Fittings (other than reducers)	Reducers (mm x mm)	Loss through fittings, h_p (m)	No. of appliances supplied by pipe section
1	398.5	4.40	17.0	0.019	75	0.007	0.119	1 gate valve, 1 tee, 2 elbows	-	0.189	270
2	288.0	2.80	4.0	0.019	65	0.013	0.052	1 gate valve, 1 tee	75 x 65	0.084	197
3	262.5	2.70	12.0	0.019	65	0.012	0.144	1 gate valve, 1 tee	-	0.075	161
4	218.5	2.50	6.5	0.019	65	0.010	0.065	1 gate valve, 1 tee,	-	0.065	145
5	214.5	2.45	21.0	0.019	65	0.009	0.189	1 tee, 1 elbow	-	0.076	144
6	195.0	2.40	12.0	0.019	65	0.008	0.096	1 gate valve, 1 tee	-	0.060	120
7	156.0	1.90	12.0	0.019	65	0.004	0.048	1 tee	-	0.033	96
8	117.0	1.40	12.0	0.019	50	0.012	0.144	1 gate valve, 1 tee,	65 x 50	0.061	72
9	78.0	1.20	12.0	0.019	50	0.009	0.048	1 gate valve, 1 tee,	-	0.043	48
10	39.0	0.80	15.0	0.019	50	0.004	0.060	1 gate valve, 1 tee, 1 elbow	-	0.025	24
11	26.0	0.50	3.0	0.019	40	0.009	0.027	1 gate valve, 1 tee	50 x 40	0.017	16
12	13.0	0.35	3.5	0.019	32	0.011	0.039	1 gate valve, 1 tee, 1 elbow	40 x 32	0.030	8
13	8.0	0.27	0.5	0.019	32	0.007	0.004	1 tee	-	0.011	4
14	5.0	0.17	1.5	0.019	25	0.010	0.015	1 tee	32 x 25	0.013	2
15	3.0	0.10	3.5	0.019	20	0.015	0.053	1 gate valve, 4 elbows	25 x 20	0.026	1
Total			135.5				1.103			0.808	Cumulative: 270

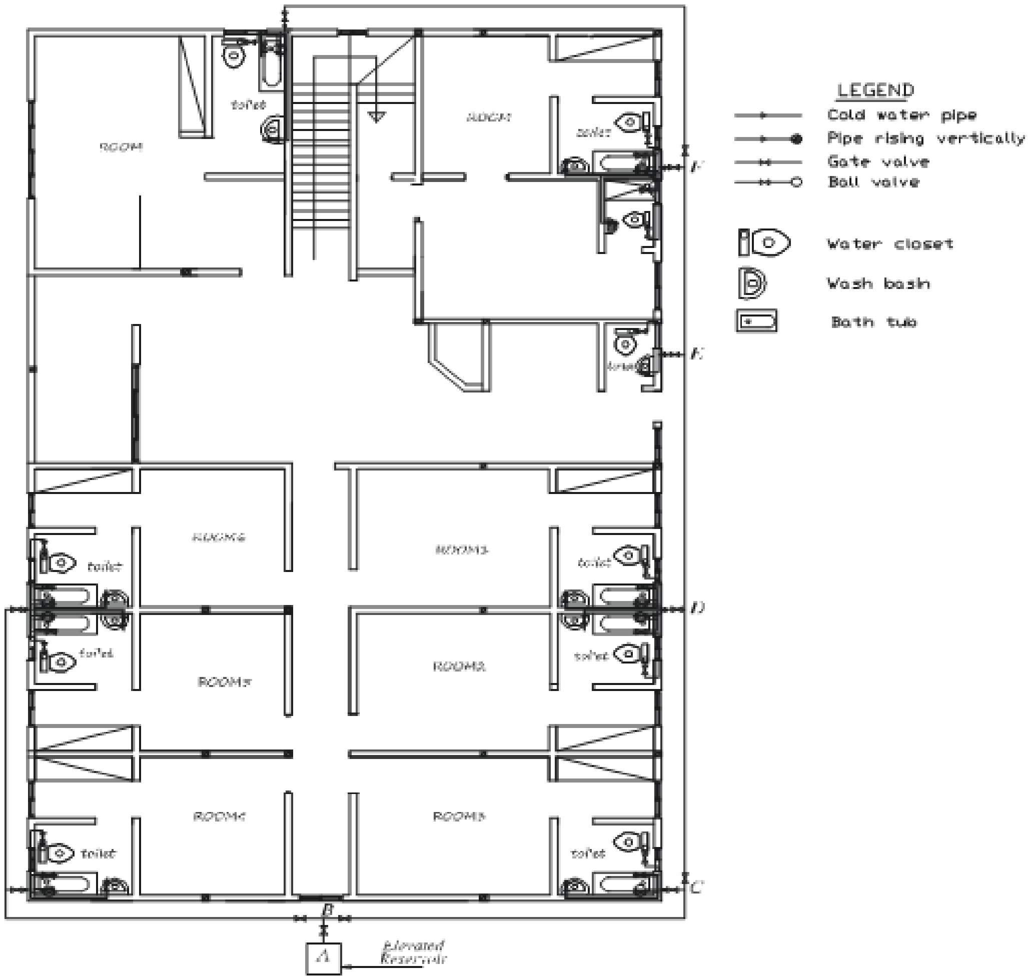

Figure 9. Typical Floor Plan of Water Distribution to a 36-Room Hotel Building

B. A 36 – Room Hotel Building

A typical floor plan for the three-floor hotel building for this case study is shown in Fig. 9 while the water distribution isometric sketch is shown in Fig. 10. The summary of calculations for pipe sizing and head loss components is Table 6. The reservoir discharge is 3.7 l/s at an available head of 3 m. The total frictional loss in the first index run is 2.130m while that due to pipe fittings is 1.200m (hence a total of 3.330m) with a fraction of loss due to pipe fittings of 0.360.

Now, applying the regression equation which relates length of first index pipe run to the loss fraction due to fittings (Eqn. 6),

$$y = 0.294 - 0.0012x_1 + 1.6 \times 10^{-5} x_1{}^2$$

gives

$$y = 0.294 - 0.0012 \times 86.3 + 1.6 \times 10^{-5} \times 86.3^2 = 0.310$$

as the length of the index run is 86.3m. This regression result of 0.310, being at variance from the case study result of 0.360 by 13.8%, validates the regression equation.

Furthermore, applying the relevant derived model equation (Eqn. 7) which relates the reservoir discharge to the fraction of loss due to fittings

$$y = 0.286 - 0.04x_2 + 0.016x_2{}^2$$

we obtain

$$y = 0.286 - 0.04(3.7) + 0.016(3.7)^2 = 0.357$$

Thus, the fraction of 0.357 represents a decrease of only 7.3% below that obtained from the case study result and, thus, validates the regression equation. Also applying the relevant regression equation (Eqn. 8) for number of sanitary appliances supplied in the index pipe run

$$y = 0.275 + 1 \times 10^{-4} x_3 + 2 \times 10^{-6} x_3{}^2$$

we obtain (with 108 appliances)

$$y = 0.275 + 1 \times 10^{-4} \times 108 + 2 \times 10^{-6} \times 108^2 = 0.309$$

The value of 0.309 is, thus, only 14.2% at variance with the case study result. Thus, the regression equation is acceptable for approximation purposes.

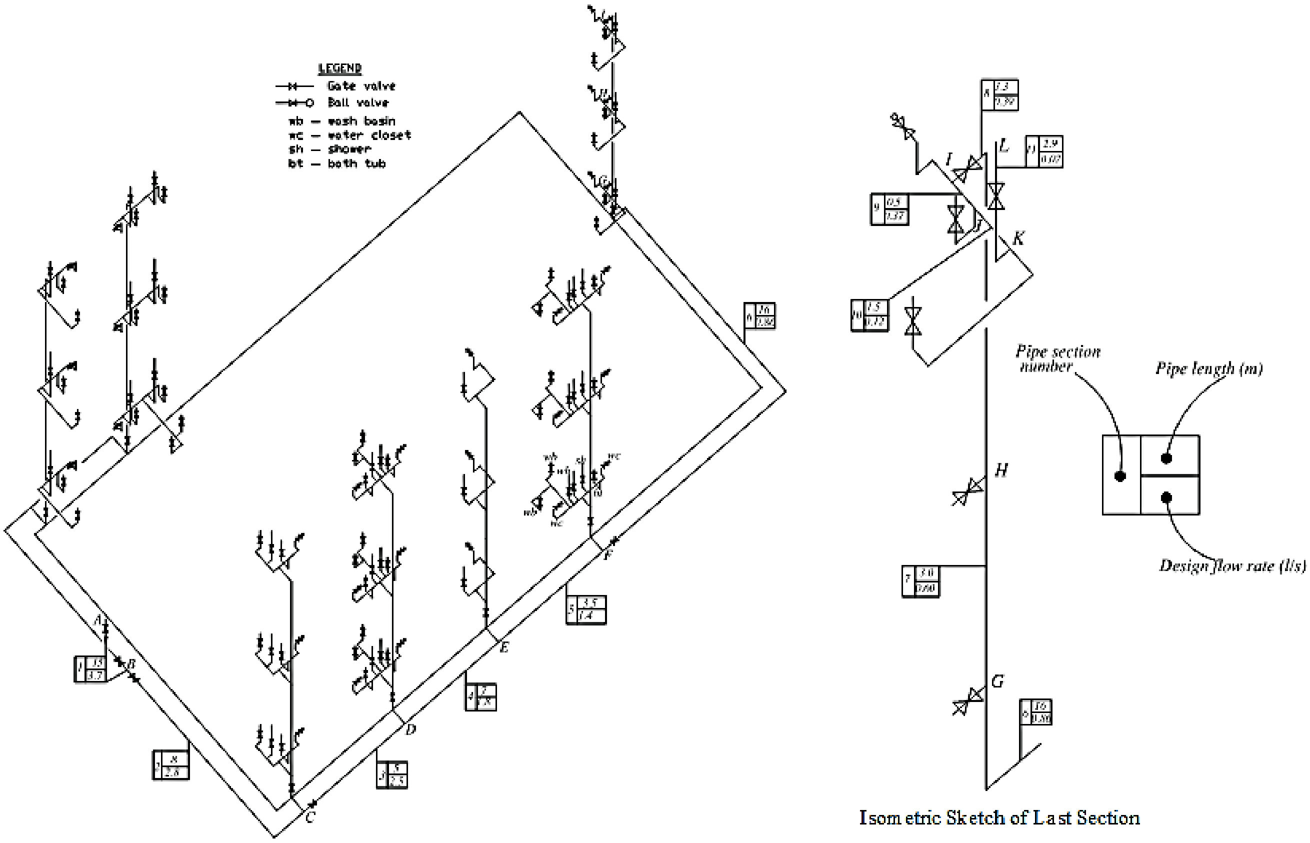

Figure 10. Isometric Sketch of Distribution to a 36-Room Hotel Building

TABLE VI. PIPE SIZING AND CALCULATION OF HEAD LOSS COMPONENTS FOR DISTRIBUTION TO 36 – ROOM HOTEL BUILDING

Pipe section no. (see Figs. 9 and 10)	Loading unit	Design Flow (l/s)	Pipe Length (m)	Permissible max. H/l	Diameter (mm)	Actual H/L	Frictional Loss (m)	Reducer (mm x mm)	Other fittings	Loss thru fittings (m)	No. of appliances supplied by pipe section
1	411.0	3.70	25.0	0.046	65	0.019	0.475	-	2el, 1 tee, 1g.v	0.237	108
2	271.5	2.80	10.0	0.046	50	0.038	0.380	65 x 50	1el, 1 tee, 1g.v	0.329	78
3	225.0	2.50	5.0	0.046	50	0.030	0.150	-	1 tee, 1g.v	0.186	66
4	129.0	1.80	7.0	0.046	50	0.019	0.133	-	1 tee	0.086	42
5	118.5	1.40	3.5	0.046	50	0.012	0.042	-	1 tee	0.052	36
6	46.5	0.86	25.0	0.046	40	0.023	0.575	50 x 40	3el, 1 tee, 1g.v.	0.110	12
7	31.0	0.60	3.0	0.046	32	0.030	0.090	40 x 32	1 tee	0.060	8
8	15.5	0.39	3.3	0.046	25	0.045	0.149	32 x 25	1el, 1 tee, 1 g.v.	0.100	4
9	13.5	0.37	0.5	0.046	25	0.040	0.020	-	1 tee	0.058	3
10	3.5	0.12	1.5	0.046	20	0.015	0.023	25 x 20	1 tee	0.016	2
11	2.0	0.07	2.5	0.046	15	0.037	0.093	20 x 15	2el, 1g.v.	0.015	1
Total			86.3				2.130			1.200	Cumulative: 108

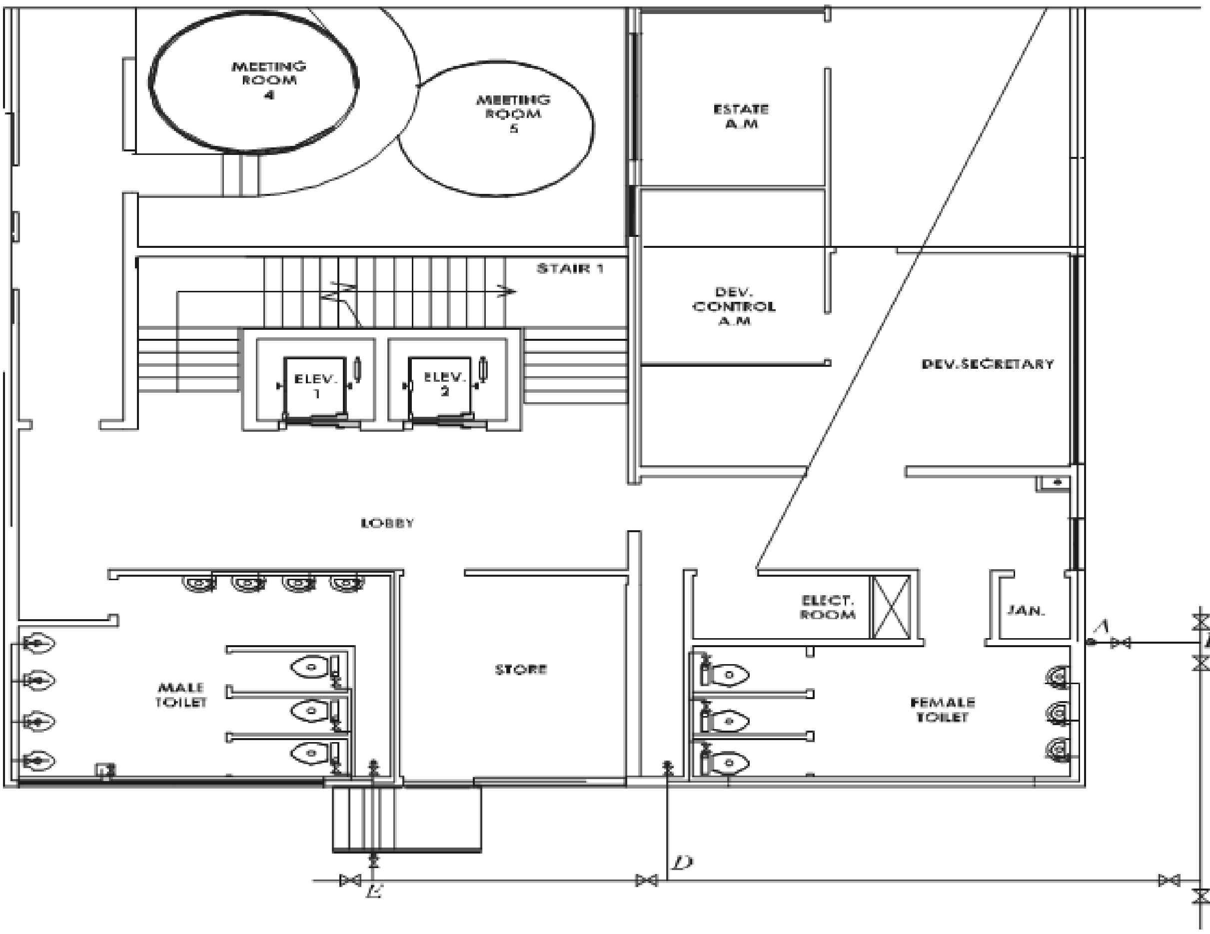

Figure 11. Typical Part Floor Plan for Distribution to 250- Occupancy Office Building

C. A 250 – Occupancy Office Building

A typical part floor plan of the building of this case study is shown in Fig. 11 and the isometric sketch of its water distribution first index run is shown in Fig. 12, while the summary of calculations of pipe sizes and head loss components is given in Table 7. A reservoir discharge of 2.80 l/s at an available head of 4 m resulted in a total frictional loss of 1.965m and a loss through fittings of 0.925m; hence a total head loss of 2.890m and a fraction of loss due to fittings of 0.320.

Applying the relevant regression model equation (Eqn. 6) relating index run length and the fitting loss fraction

$$y = 0.294 - 0.0012x_1 + 1.6 \times 10^{-5} x_1{}^2$$

we obtain for an index length of 99m,

$$y = 0.294 - 0.0012 \times 99 + 106 \times 10^{-5} \times 99^2 = 0.332$$

This regression model value is, thus, at variance with the case study value of 0.320 by only 3.7% and the regression equation is, therefore, acceptable.

Also, applying the relevant derived regression model equation (Eqn. 7) which relates the reservoir discharge to the fraction of loss due to fittings

$$y = 0.286 - 0.04\, x_2 + 0.016x^2$$

gives

$$y = 0.286 - 0.04(2.8) + 0.016(2.8)^2 = 0.299$$

which is close to 0.320 obtained in this case study (this fraction representing only a 6.5% decrease below the result of the case study). The regression equation is, thus, acceptable for approximation purposes.

Further applying the equation relating number of sanitary appliances to the fitting loss fraction (Eqn. 8)

$$y = 0.275 + 1 \times 10^{-4} x_3 + 2 \times 10^{-6} x_3{}^2$$

for 95 appliances installed in the case study building yields

$$y = 0.275 + 1 \times 10^{-4} \times 95 + 2 \times 10^{-6}\, 95^2 = 0.303$$

and the variance of this result from the case study result of 0.320 is only by 5.3%, which is acceptable, being less than 20%.

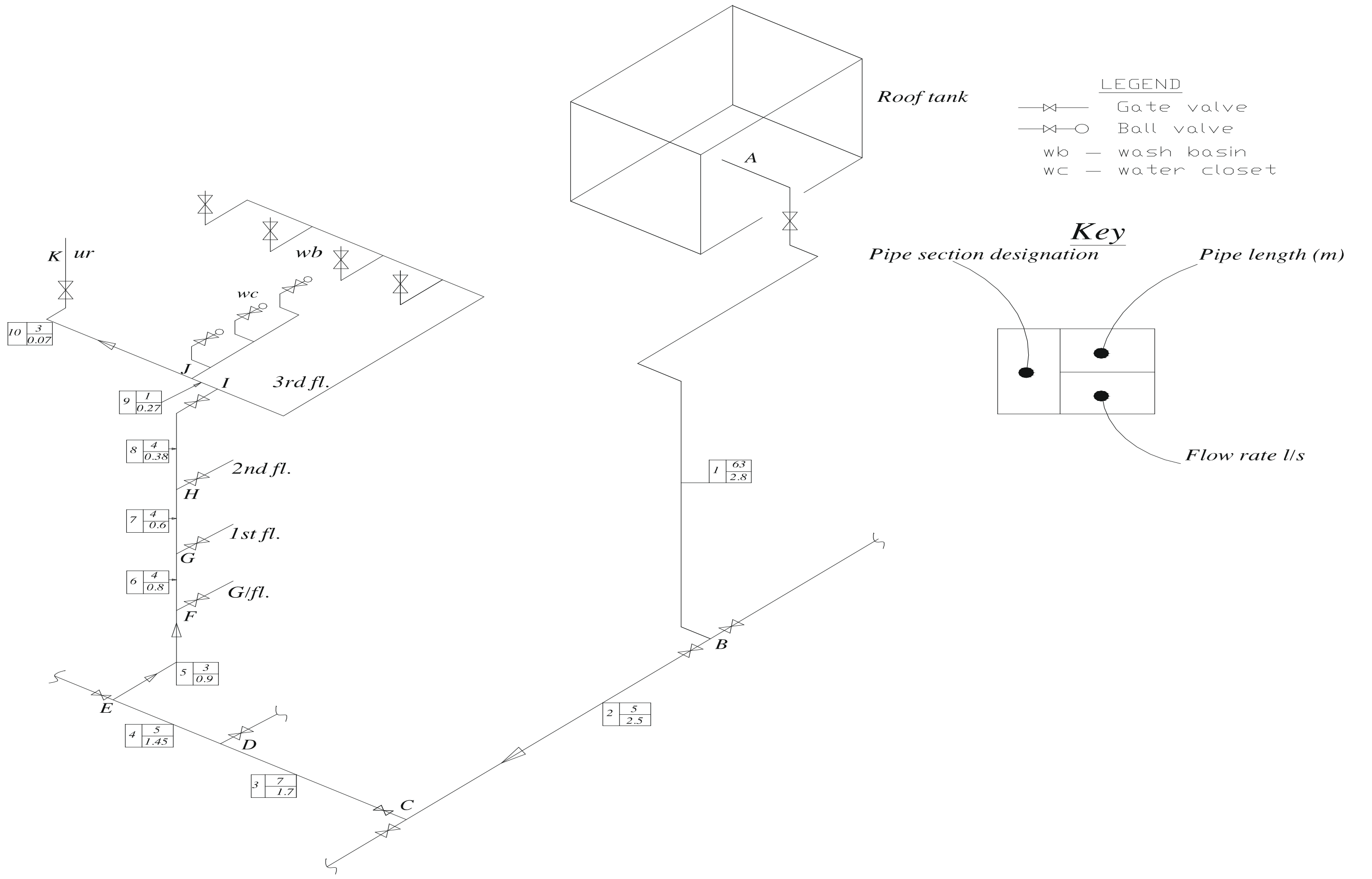

Figure 12. Isometric Sketch of Distribution to First Index Run of 250-Occupancy Office Building

TABLE VII. PIPE SIZING AND CALCULATION OF HEAD LOSS COMPONENTS FOR DISTRIBUTION TO 250 – OCCUPANCY OFFICE BUILDING

Pipe Section no. (see Figs. 11 and 12)	Loading Unit	Design Flow (l/s)	Pipe length (m)	Permissible maximum $H/$l	Diameter (mm)	Actual H/l	Frictional Loss (m)	Reducers (mm x mm)	Other Fittings	Loss thru fittings (m)	No. of appliances supplied by pipe section
1	304	2.80	63	0.04	65	0.013	0.819	-	6 elbows, 1 gate valve, 1 tee	0.318	98
2	211	2.50	5	0.04	50	0.030	0.150	65 x 50	1 g.v., 1 tee	0.196	70
3	147	1.70	7	0.04	50	0.017	0.119	-	1 g.v.	0.010	58
4	105	1.45	5	0.04	50	0.014	0.070	-	1 ell, 1 g.v., 1 tee	0.103	45
5	56	0.90	3	0.04	40	0.025	0.075	50 x 40	1 tee	0.055	32
6	42	0.80	4	0.04	40	0.019	0.316	-	1 tee	0.041	24
7	28	0.60	4	0.04	32	0.030	0.120	40 x 32	1 tee	0.060	16
8	14	0.38	4	0.04	25	0.040	0.160	32 x 25	1 ell, 1 g.v., 1 tee	0.095	8
9	8	0.27	1	0.04	25	0.022	0.022	-	1 tee	0.031	4
10	2	0.07	3	0.04	15	0.038	0.114	25 x 15	2 elbow, 1 g.v.	0.016	1
Total			99				1.965			0.925	Cumulative: 95

TABLE VIII. SUMMARY OF COMPUTATIONS FOR VALIDATING REGRESSION MODEL EQUATIONS FOR DISTRIBUTION WITHIN BUILDINGS

S/No.	Case Study	Regression Model Equation	Independent Variable x		Dependent Variable y: Ratio of Fitting Loss to Total Loss (i.e. Fraction of Loss due to Fittings)			Remarks*
			Definition	Value	Calculated from Regression Equation	Calculated by Usual Procedure	% Deviation of Regression Model from Usual Procedure	
1	448 – Bed Student Hostel	$y = 0.294 - 0.0012x_1 + 1.6 \text{ x } 10^{-5}{x_1}^2$	Length of Index Pipe Run, x_1	135.5 m	0.425	0.423	0.5	Equation is Validated
		$y = 0.286 - 0.04x_2 + 0.016{x_2}^2$	Reservoir Discharge x_2	4.4l/s	0.420	0.423	7.0	"
		$y = 0.275 + 1 \text{ x } 10^{-4}x_3 + 2 \text{ x } 10^{-6}{x_3}^2$	Number of Sanitary Appliances x_3	270	0.448	0.423	5.9	"
2	36 – Room Hotel Building	$y = 0.294 - 0.0012x_1 + 1.6 \text{ x } 10^{-5}{x_1}^2$	Length of Index Pipe Run x_1	86.3m	0.310	0.360	13.8	"
		$y = 0.286 - 0.04x_2 + 0.016{x_2}^2$	Reservoir Discharge x_2	3.7l/s	0.357	0.360	7.3	"
		$y = 0.275 + 1 \text{ x } 10^{-4}x_3 + 2 \text{ x } 10^{-6}{x_3}^2$	Number of Sanitary Appliances x_3	108	0.309	0.360	14.2	"
3	250 – Occupancy Office Building	$y = 0.294 - 0.0012x_1 + 1.6 \text{ x } 10^{-5}{x_1}^2$	Length of Index Pipe Run x_1	99m	0.332	0.320	3.7	"
		$y = 0.286 - 0.04x_2 + 0.016{x_2}^2$	Reservoir Discharge x_2	2.8l/s	0.299	0.320	6.5	"
		$y = 0.275 + 1 \text{ x } 10^{-4}x_3 + 2 \text{ x } 10^{-6}{x_3}^2$	Number of Sanitary Appliances x_3	95	0.303	0.320	5.3	"

*Deviations less than 20% from the usual procedure are considered acceptable for approximation purposes and, hence, validate the relevant regression equation.

V. SUMMARY AND CONCLUSIONS

Comparisons have been made between results of the regression equations and those of three case studies as summarized in Table 8. The table shows that, within the ranges of values of system parameters utilized in the study, all case studies validate the respective regression equations for predicting the fractions of head loss due to fittings and friction in composite index pipe runs for varying system parameters. The appropriate ranges of values of system parameters for application of the regression results are between 28 and 140m of first index run, between 0.6l/s and 4.4l/s reservoir discharge, and between 8 and 120 sanitary appliances.

Hence, the total head loss in a given index pipe run can quickly be estimated by adding the relevant fraction due to fittings (obtained from the relevant model equation or graph) to the total frictional loss; the frictional loss being normally easier to calculate than the total fitting loss.

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