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Validation of Regression Models for the Fraction of Fitting Loss in Index Pipe Runs (Part 2: Water Distribution to Groups of Buildings)

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Abstract- In many practical situations, the approximation of the pressure loss due to pipe fittings in the first index run of a gravity-flow water distribution system (with the ultimate aim of estimating the total pressure loss in the index run), is a time-saving effort. In this regard, several percentages of the total frictional loss have been suggested to account for the total fitting loss. However, as those suggested percentages lack statistical basis, earlier studies by the authors had arrived at regression equations for predicting the fractions of the total head loss that are due to pipe fittings in index pipe runs. The present study aims at validating those regression models, for the scenarios of distribution to groups of buildings, by comparison of the regression results with those of case studies of distribution to existing functional groups of buildings. All regression equations appear to be valid within the limits of values of system parameters utilized in obtaining the regression models; as their percentages of variance from results of the case studies are all less than 20%; this percentage being a suggested threshold value for checking the validity.

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

I. Introduction

As an aid in the estimation of pressure losses in index pipe runs in gravity-flow water distribution systems, several factors or percentages have been proposed to be applied on the frictional head loss to account for the loss through all installed pipe fittings in the index run [1, 2, 3, 4, 5, 6, 7, 8, 9, 10]. Hence, the total head loss in the first index pipe run is obtained by increasing the frictional loss by those factors or percentages. However, as those factors or percentages show no statistical basis for their derivation, earlier studies had been done by the authors to obtain regression model equations for obtaining the fraction of loss due to pipe fittings for varying system parameters, such parameters being the length of index pipe run, number of sanitary appliances supplied, reservoir discharge, and number of buildings supplied [11, 12, 13, 14, 15]. In the regression equations, the fraction of loss due to fittings is the dependent variable, denoted as y; while each of the varying system parameters is an independent variable, denoted as x. Furthermore, a recent study had validated the regression equations obtained for the scenario of water distribution within buildings [16]. The present study aims at validating the regression model equations obtained for distribution to groups of buildings, by comparing the results of the model equations with those obtained from case studies of completed and functional installations.

II. Method of Study

Using a water distribution configuration to a group of uniformly arranged buildings (Fig. 1), the total frictional head loss and the total head loss due to pipe fittings were generated for varying system complexities. The variations in system complexities were attained by a progressive increase in the number of buildings, and the necessary analyses were carried out for each step of increase.

The frictional head loss calculations were done using the graphical form of Hazen-Williams formula, as was also utilized in the recent study on distribution within buildings [16], while the losses through pipe fittings h_p in the index pipe run were obtained from the equation:

$$h_p = 0.08256kd^{-4}q^2 \quad (1)$$

where k = head loss coefficient for the particular fitting type (obtained from [17])

d = pipe diameter (in m^3/s)

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

as was also utilized in the recent study [16].

Thus, in Fig. 1, an elevated water storage supplies the uniformly arranged buildings. As a first step, the analysis of losses due to friction and fittings is done for the pipe run from A and E and up to the farthest appliance supplied in bungalow 1 by the branch from E (considering the extension of the main distribution pipe from E towards P, and the extension on the branch from point H towards K, in Fig. 1, as non-existent).

In the second step, Bungalow 2 is added on in the analysis (considering only the extension from H towards K, L, M, N and O, in Fig. 1, as existing). In the third step, Bungalow 3 is added on for the analysis; and in subsequent steps other bungalows are added on in like manner. The progressive increase in number of bungalows in successive steps of the analysis provides the variation of the complexity of pipework in terms of number of buildings supplied from the reservoir, length of first index pipe run, total design flow rate, and number of sanitary appliances served.

Following the same calculation methods as were adopted in the study for validating the regression equations for water distribution within buildings [16], Table 1 was obtained. The table gives a summary of the calculated total losses due to friction and fittings as well as the ratios of loss due to fittings to total loss for the varying complexities of pipework of the distribution layout of Fig. 1.

Values in Table 1 were subsequently utilized for a regression analysis for distribution to groups of buildings. The Microsoft Office Excel graphical program was utilized, and this gave the regression equations and measures of correlation r^2 and r [18] shown in Fig. 2 and Table 2.

TABLE I. RATIOS OF LOSS THROUGH FITTINGS TO TOTAL LOSS FOR VARYING PIPE WORK COMPLEXITY (FOR WATER DISTRIBUTION TO GROUPS OF BUILDINGS)

1	2	3	4	5	6	7	8
No. of buildings	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
1	68.0	0.88	17	1.659	0.397	2.054	0.193
2	92.6	1.35	34	1.625	0.539	2.164	0.249
3	98.3	1.85	51	1.988	0.699	2.657	0.260
4	122.9	2.35	68	1.720	0.787	2.507	0.314
5	128.6	2.65	85	2.025	0.929	2.952	0.315
6	153.2	2.90	102	1.945	0.956	2.901	0.330
7	158.9	3.20	119	1.875	1.096	2.971	0.369
8	183.5	3.70	136	1.625	1.194	2.819	0.424
9	189.2	4.00	153	1.705	1.296	3.001	0.432
10	213.8	4.25	170	1.798	1.513	3.311	0.457
11	219.5	4.35	187	1.937	1.576	3.513	0.949
12	244.1	4.60	204	1.894	1.625	3.519	0.462
13	249.8	4.64	221	1.555	1.280	2.835	0.451
14	274.4	4.80	238	1.750	1.511	3.261	0.463
15	280.1	5.00	255	1.447	1.442	2.889	0.499
16	304.7	5.60	272	1.749	1.636	3.385	0.483

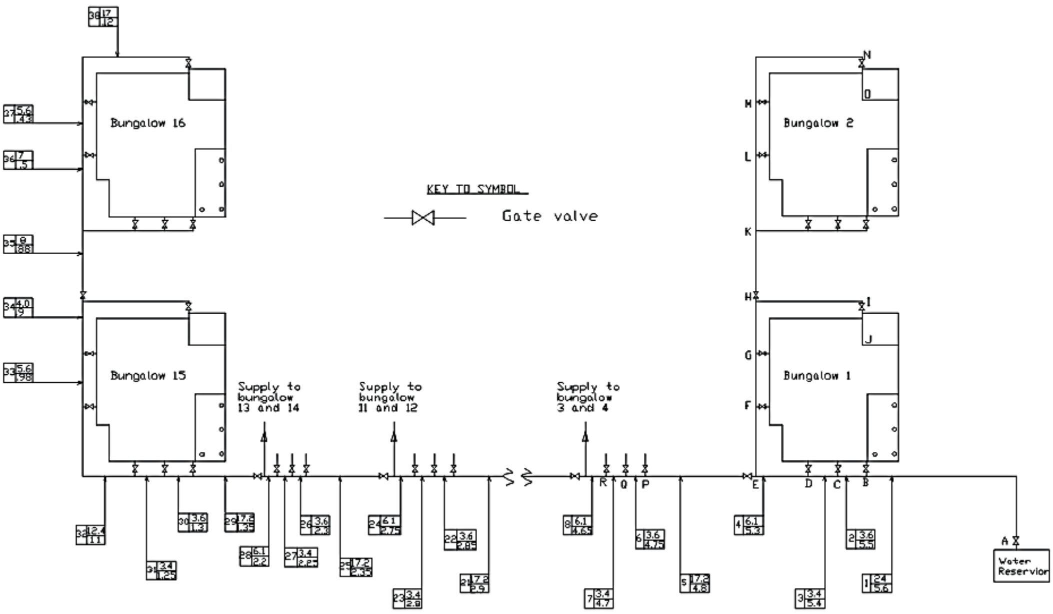

Figure 1. Water Distribution Layout to a Group of 16 Bungalows

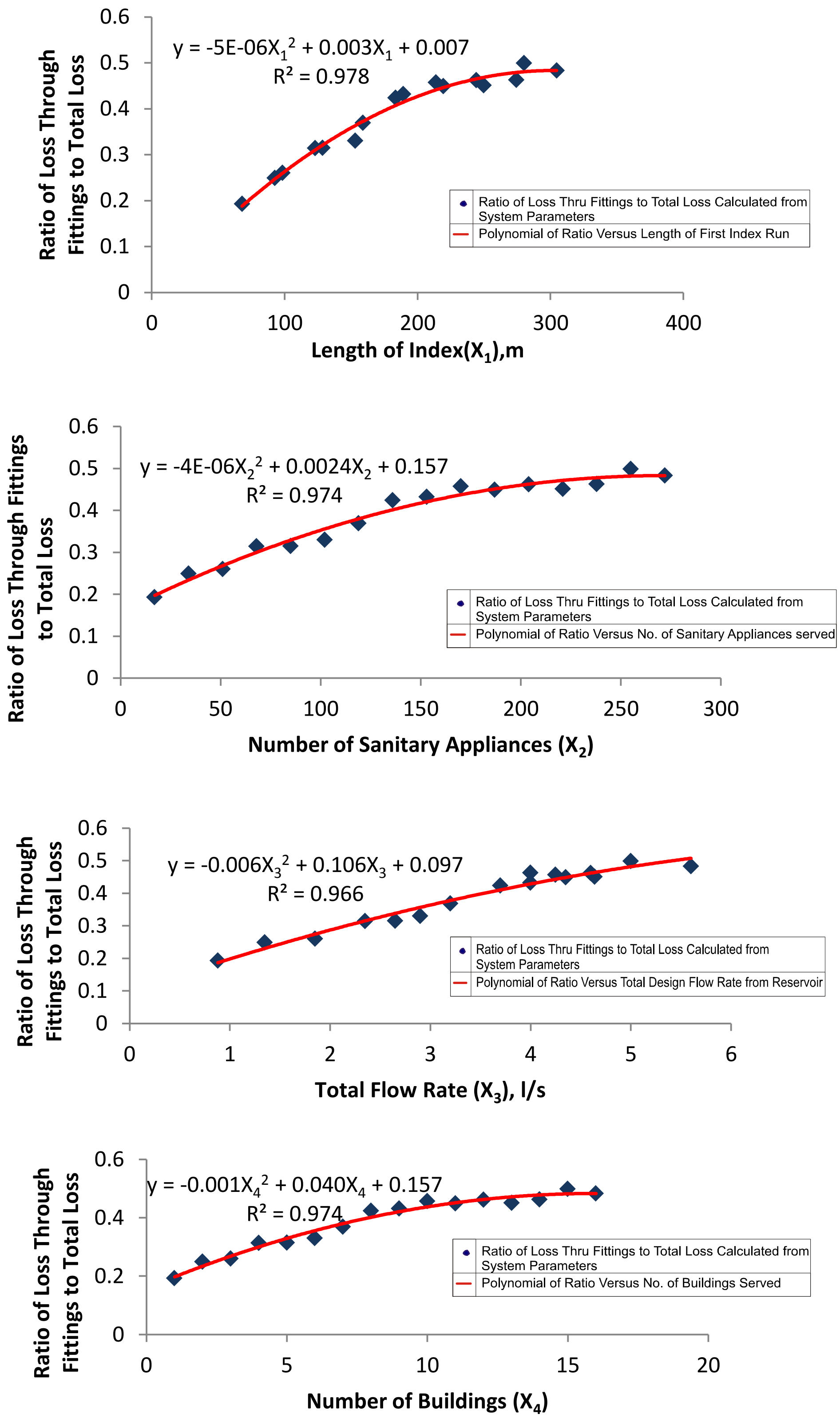

Figure 2. Variation of Ratio of Loss through Fittings to Total Head Loss with Pipework Complexity (for Distribution to Groups of Buildings)

TABLE II. RESULTS OF REGRESSION ANALYSIS FOR DISTRIBUTION TO GROUPS OF 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)	$y = 0.007 + 0.003x_1 - 5 \times 10^{-6} x_1{}^2$	0.978	0.989
Number of Sanitary Appliances, x_2	$y = 0.157 + 0.0024\, x_2 - 4 \times 10^{-6} x_2{}^2$	0.974	0.987
Reservoir Discharge, x_3 (l/s)	$y = 0.097 + 0.106\, x_3 - 0.006\, x_3{}^2$	0.966	0.983
Number of Buildings Supplied, x_4	$y = 0.157 + 0.04\, x_4 - 0.001\, x_4{}^2$	0.974	0.987

III. VALIDATION OF MODEL EQUATIONS

The validation of the regression equations is now carried out, in the manner of the validation of the regression equations for distribution within buildings [16], by comparison of results of case studies of completed and functional water distribution systems with the results obtained by application of the regression equations. The results are the ratios of head loss due to fittings to the total head loss, which are needed for approximating the fitting loss component.

In the comparisons that follow, any variance not greater than 20% from the result of a case study, for the corresponding regression model result, is regarded as acceptable for approximating purposes; due to the suggestion by Keller and Bliesner [19] that a 20% addition could be allowed in estimating head losses. In this study, three distribution systems to groups of buildings are taken as case studies.

A. A 12 – Unit Residential Housing Estate

The estate under study comprises of twelve buildings on two floors. The water distribution layout of the estate is shown in Fig. 3, while a typical water distribution building floor plan and an isometric sketch of the first index pipe run are shown in Figs. 4 and 5, respectively.

From Table 3 which summarizes the relevant calculations, the fraction of head loss due to fittings is obtained as 0.415.

Now, the reservoir discharge for this case study is 3.6 l/s with an available head of 3.2 m and a first index pipe run of 181.0m.

Applying the regression equation which relates to the first index run pipe length for this case study which is 181.0m,

$$y = 0.007 + 0.003x_1 - 5 \times 10^{-6} x_1{}^2 \tag{2}$$

or $y = 0.007 + 0.003 \times 181 - 5 \times 10^{-6} \times 181^2 = 0.386$

The regression equation result of 0.386 is, thus, at variance with the case study result of 0.415 by only 7.0%. The regression equation is, therefore, an acceptable approximation for the fraction of the loss due to pipe fittings.

Further applying the regression equation which relates the fitting loss fraction to the number of sanitary appliances

$$y = 0.157 + 0.0024x_2 - 4\, x\, 10^{-6} x_2{}^2 \tag{3}$$

for 224 appliances, we obtain

$$y = 0.157 + 0.0024 \times 224 - 4 \times 10^{-6} \times 224^2 = 0.494$$

This regression result is, thus, at variance with the case study fraction of 0.415 by 19.0%. As this is less than 20%, the regression equation is considered acceptable for approximation purposes.

Applying the regression equation which relates the fraction due to pipe fittings and the reservoir discharge, for the same available head of 3.2m, the resulting fraction is obtained from

$$y = 0.097 + 0.106x_3 - 0.006\, x_3{}^2 \tag{4}$$

as

$$y = 0.097 + 0.106 \times 3.6 - 0.006(3.6^2) = 0.401$$

This fraction being at variance with that of the case study by only 3.4%, is considered acceptable for approximation purposes.

Finally applying the regression equation which relates to the number of buildings for this case study having 12 buildings

$$y = 0.157 + 0.04x_4 - 0001x_4{}^2 \tag{5}$$

or

$$y = 0.157 + 0.04 \times 12 - 0.001 \times 12^2 = 0.493$$

This regression result is thus, at variance with the case study fraction of 0.415 by 18.8% (<20%). The regression model is, therefore, acceptable for approximations.

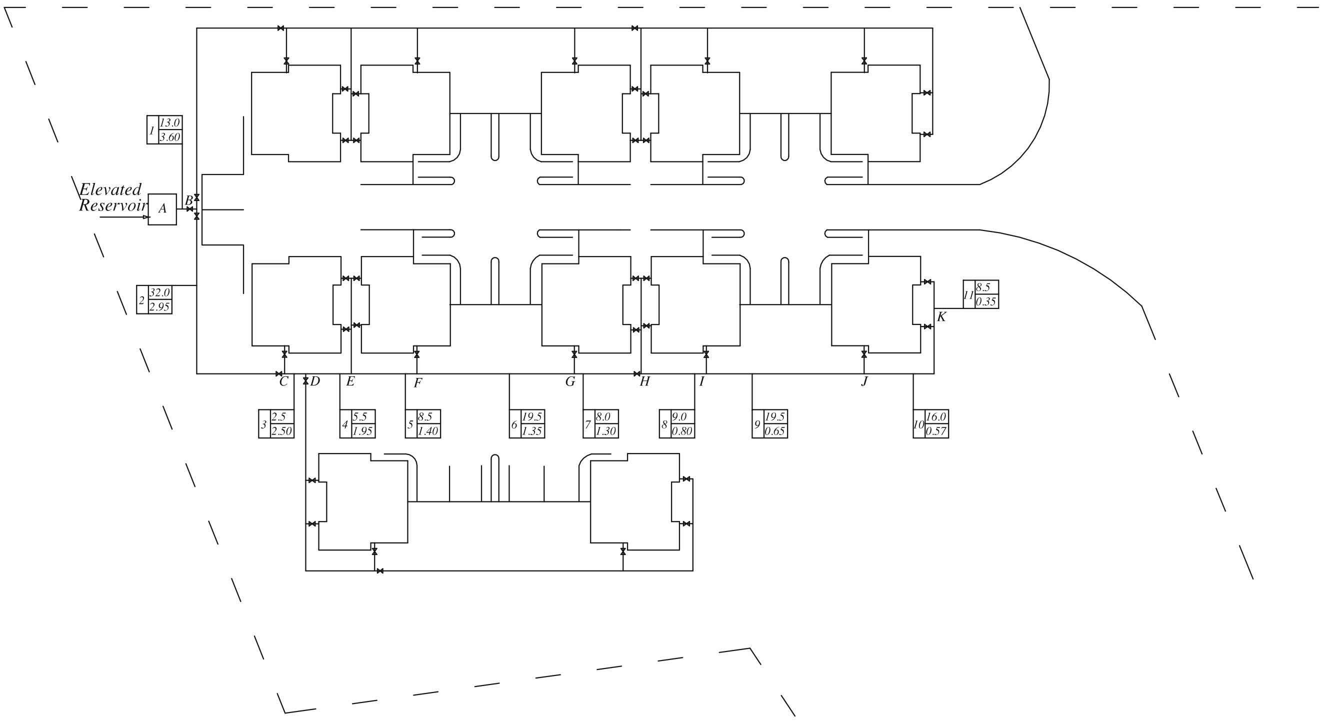

Figure 3. Water Distribution Layout to 12-Unit Residential Estate

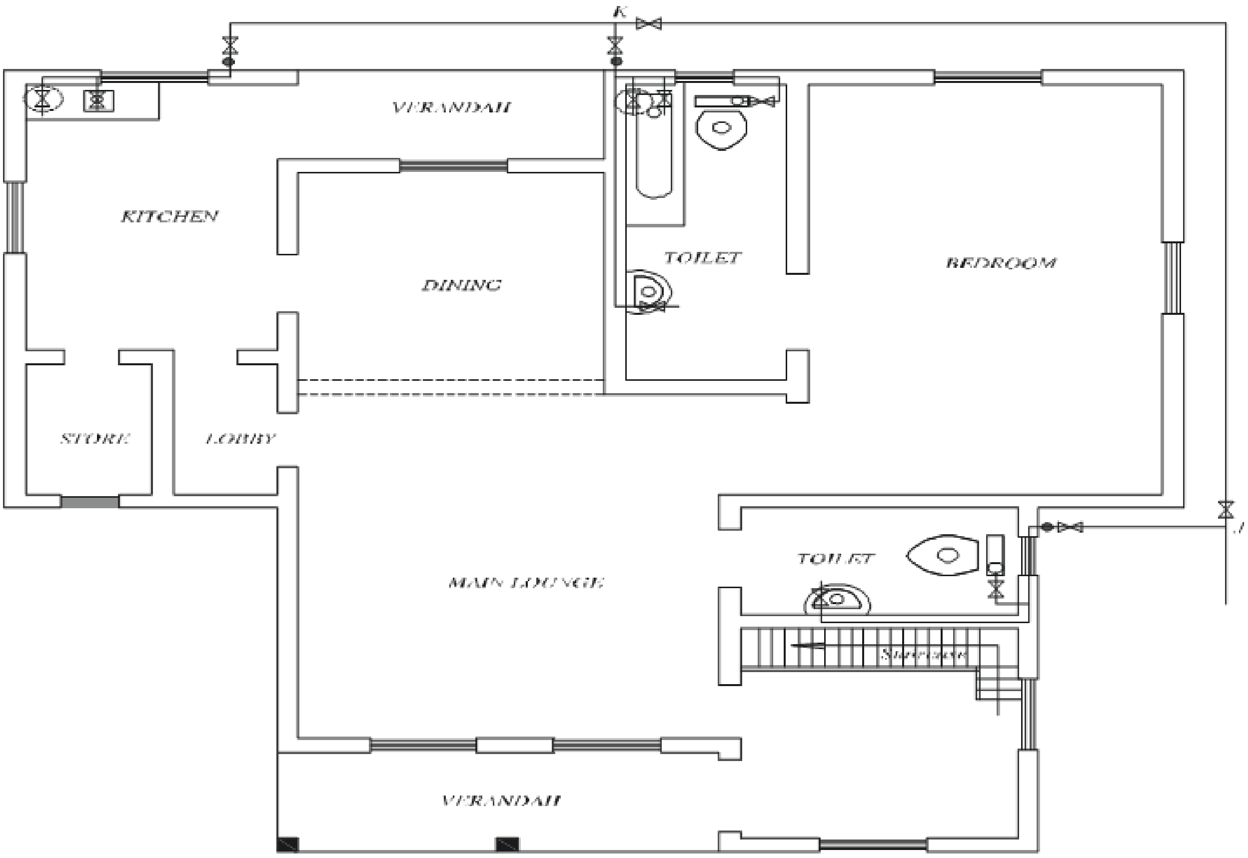

Figure 4. Typical Floor Plan of Distribution Layout to 12-Unit Residential Estate

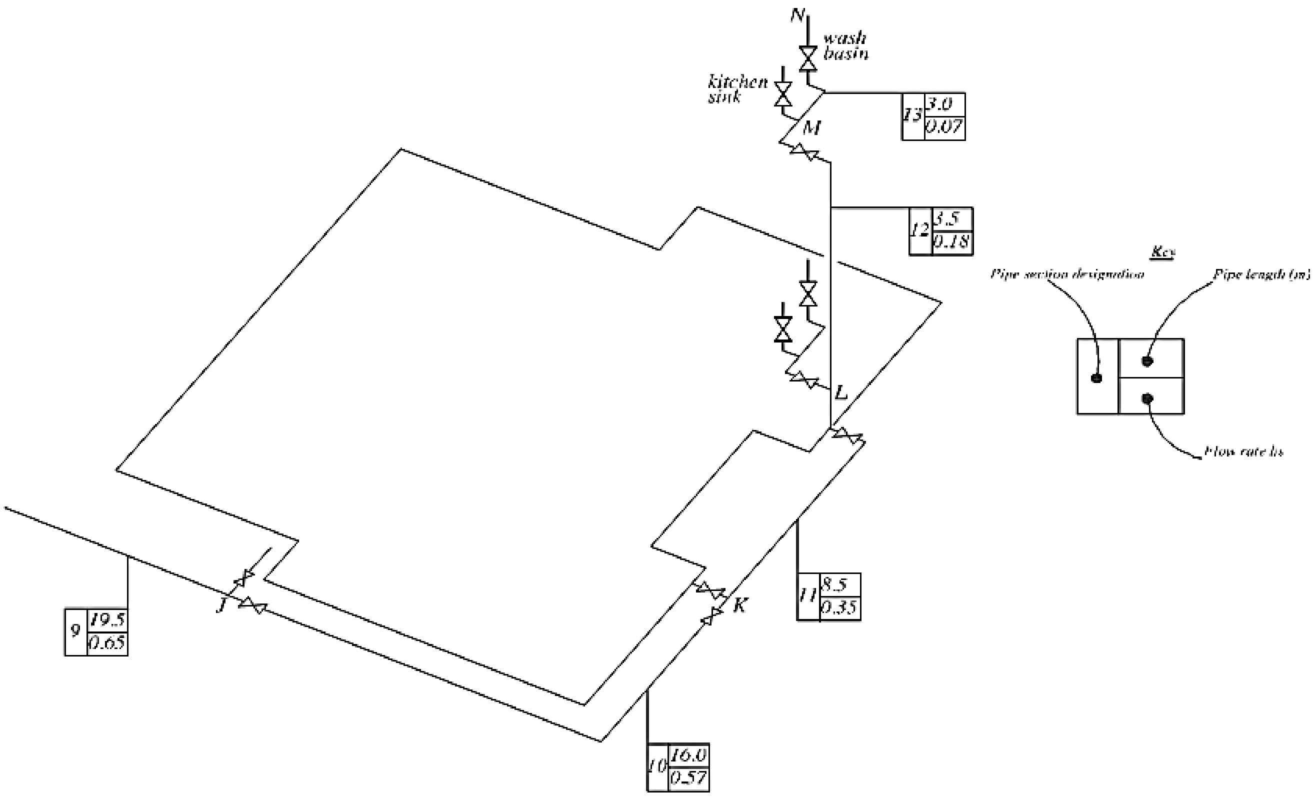

Figure 5. Isometric Sketch of Distribution to First Index Run of 12 Units Residential Estate

TABLE III. PIPE SIZING AND CALCULATION OF HEAD LOSS COMPONENTS FOR DISTRIBUTION TO 12 – UNIT RESIDENTIAL ESTATE

Pipe section no. (see Figs. 3, 4 and 5)	Loading unit	Design flow l/s	Pipe length (m)	Permissible H/L	Dia. 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	408	3.60	16.5	0.022	65	0.017	0.281	-	3el, 1g.v, 1 tee	0.442	224
2	306	2.95	36.5	0.022	65	0.014	0.511	-	3el, 1g.v, 1 tee	0.434	144
3	231	2.50	2.5	0.022	65	0.011	0.028	-	1 tee	0.058	142
4	163	1.95	5.5	0.022	65	0.007	0.039	-	1 tee	0.035	110
5	109	1.40	8.5	0.022	50	0.011	0.094	65 x 50	1 tee	0.075	50
6	102	1.35	29.5	0.022	50	0.010	0.295	-	1 tee	0.048	48
7	95	1.30	8.0	0.022	50	0.009	0.072	-	1.g.v, 1 tee	0.050	46
8	41	0.80	9.0	0.022	40	0019	0.171	50 x 40	1 tee	0.043	18
9	34	0.65	24.0	0.022	40	0.013	0.312	-	1 tee	0.027	16
10	27	0.57	26.0	0.022	40	0.010	0.260	-	1el, 1tee	0.059	8
11	10	0.35	8.5	0.022	32	0.012	0.102	40 x 32	2el, 1g.v, 1 tee	0.139	4
12	5	0.18	3.5	0.022	25	0.011	0.039	32 x 25	2el, 1g.v, 1 tee	0.100	2
13	2	0.07	3.0	0.022	20	0.008	0.024	25 x 20	2el, 1g.v, 1 tee	0.071	1
Total			181.0				2.228			1.581	Cumulative: 224

B. 3 Blocks of Terrace Building (Each Having 4 Family Units)

The distribution system serves three blocks of terrace buildings. Each building contains four units of 5-bedroom apartment. There are, thus, 12 individual apartments in the estate. The distribution layout is shown in Fig. 6, while an isometric sketch of the distribution piping in the first index run is given in Fig. 7.

The pipe sizing and head loss calculations are summarized in Table 4, from which the fraction of loss due to fittings is found to be 0.430. Applying the relevant system parameters in the respective regression equations, as was done in Section IIIA above, yields variances from the case study results of 13.0%, 15.6%, 13.0% and 14.7%. As these variances are all less than 20%, the case study validates the model equations which are, therefore, useful for approximation purposes.

C. 8 Units Each of Two Prototype Buildings

This distribution system supplies sixteen buildings comprising eight units each of two prototypes designated A and B (Fig. 8) and an isometric sketch of the distribution system in the farthest building unit is shown in Fig. 9. Pipe sizing and head loss calculations for the first index run of pipework from the reservoir are given in Table 5, from which the fraction of total head loss due to fittings is found to be 0.486. Applying the respective system parameters on the regression equations results in variances from the result of 0.486 of 12.6%, 1.2%, 16.3% and 11.3%, all of which validate the regression equations, being less than 20%.

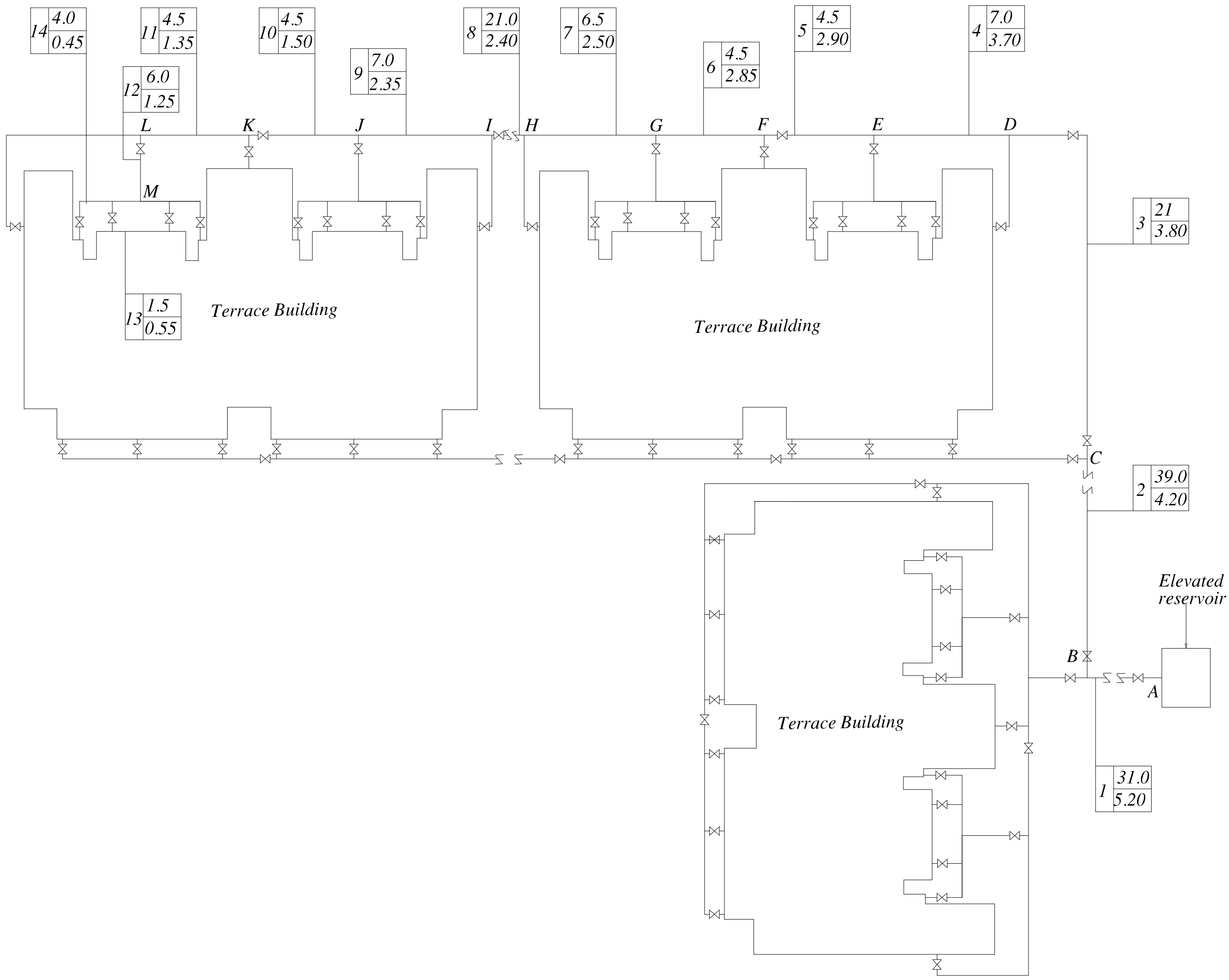

Figure 6. Water Distribution Layout to 3 Blocks of Terrace Building

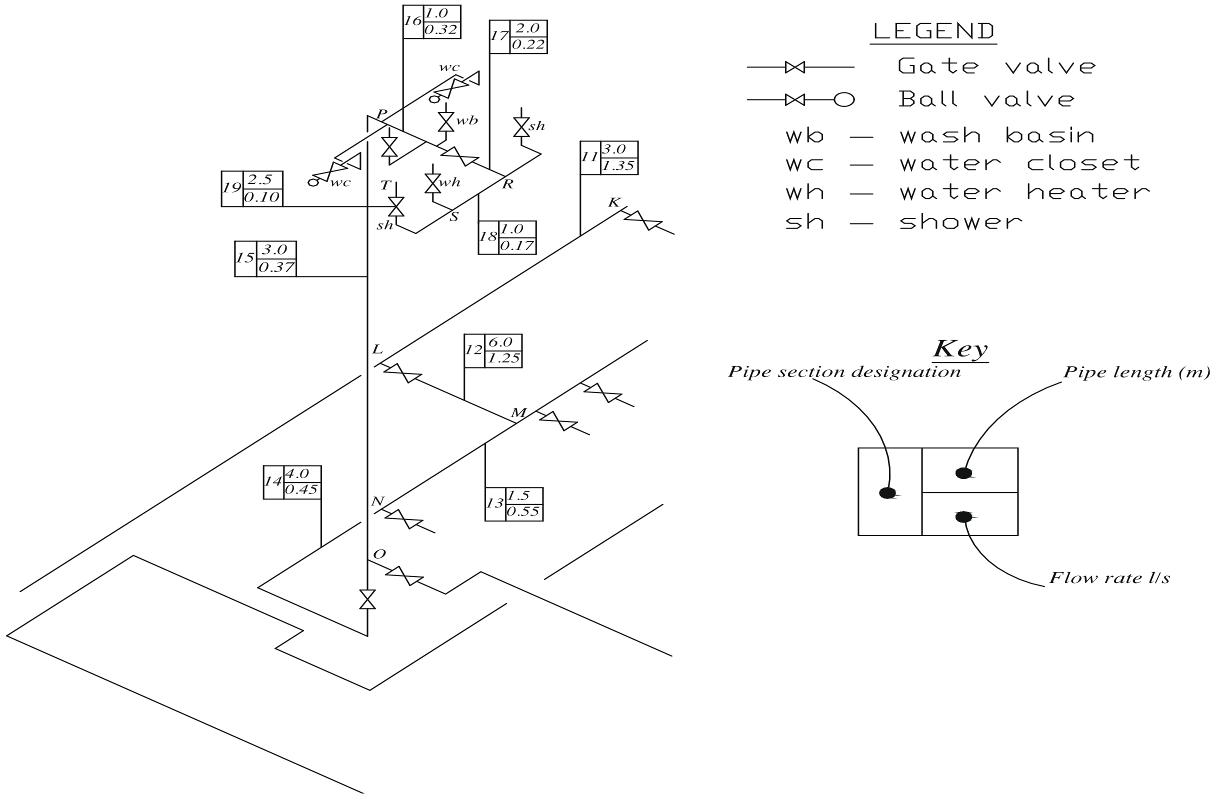

Figure 7. Isometric Sketch of Distribution to First Index Run of 3 Blocks of Terrace Building

TABLE IV. PIPE SIZING AND CALCULATION OF HEAD LOSS COMPONENTS FOR DISTRIBUTION TO 3 BLOCKS OF TERRACE BUILDING

Pipe section no. (see Figs.6 and 7)	Loading unit	Design flow(l/s)	Pipe length (m)	Permissible H/L	Dia. (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	721.5	5.20	31.0	0.027	75	0.010	0.310	-	2 el, 1g.v, 1 tee	0.265	230
2	481.0	4.20	39.0	0.027	75	0.008	0.312	-	1g.v, 1 tee	0.104	196
3	420.0	3.80	21.0	0.027	65	0.015	0.313	75 x 65	1 el, 2g. v.	0.089	180
4	410.5	3.70	7.0	0.027	65	0.018	0.126	-	1 tee	0.127	177
5	317.5	2.90	4.5	0.027	65	0.013	0.059	-	1 tee	0.078	109
6	298.5	2.85	4.5	0.027	65	0.012	0.054	-	1 tee	0.075	99
7	219.5	2.50	6.5	0.027	65	0.010	0.065	-	1 tee	0.058	78
8	210.0	2.40	21.0	0.027	65	0.009	0.019	-	1 g.v., 1 tee	0.060	73
9	200.5	2.35	7.0	0.027	65	0.008	0.056	-	1 tee	0.049	58
10	145.5	1.50	4.5	0.027	50	0.015	0.068	65 x 50	1 tee	0.063	47
11	95.5	1.35	4.5	0.027	50	0.014	0.063	-	1 tee	0.048	26
12	89.0	1.25	6.0	0.027	50	0.011	0.066	-	1 tee, 1g. v.	0.046	21
13	27.0	0.55	1.5	0.027	40	0.010	0.015	50 x 40	1 tee, 1 g. v.	0.023	13
14	22.0	0.45	4.0	0.027	32	0.018	0.072	40 x 32	2 el, 1 g.v., 1 tee	0.061	11
15	13.5	0.37	3.0	0.027	32	0.013	0.039	-	1 el, 1g.v., 2 tee	0.082	7
16	9.5	0.32	1.0	0.027	32	0.010	0.010	-	2 tee	0.032	5
17	6.5	0.22	2.0	0.027	25	0.016	0.032	32 x 25	1 tee	0.022	3
18	5.0	0.17	1.0	0.027	25	0.013	0.013	-	1 tee	0.012	2
19	3.0	0.10	2.3	0.027	20	0.015	0.038	25 x 20	2el, 1g.v.	0.010	1
Total			117.5				1.730			1.304	Cumulative: 230

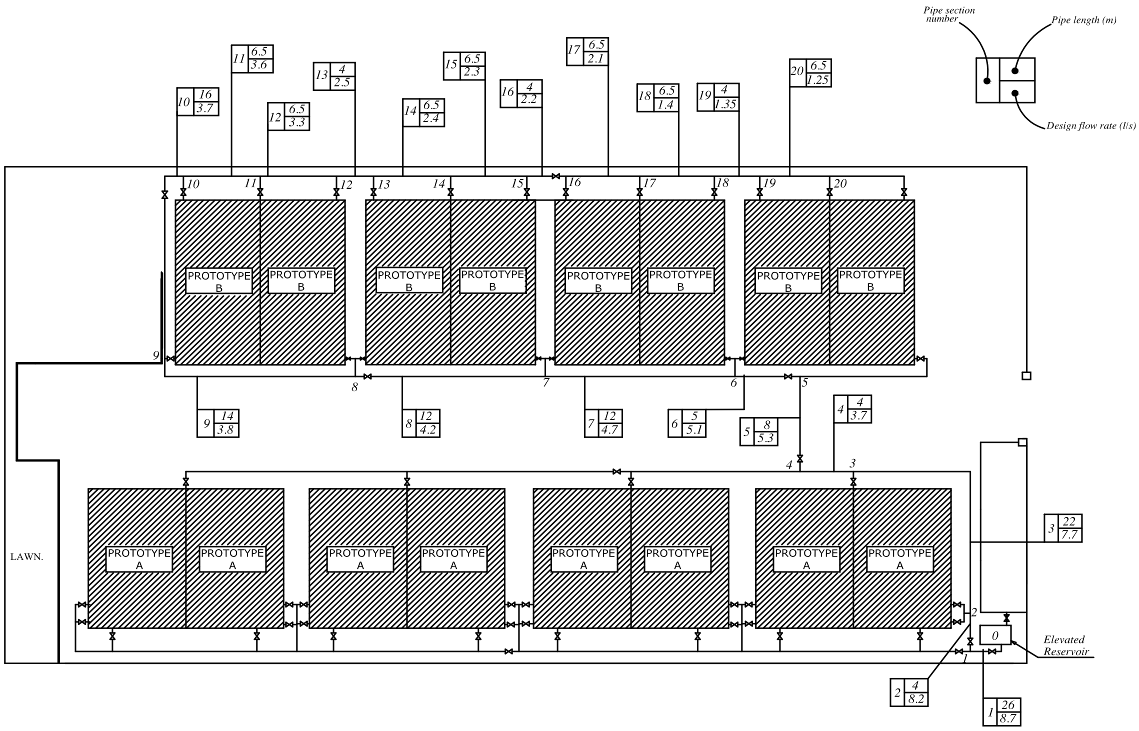

Figure 8. Water Distribution Layout to Prototype Buildings

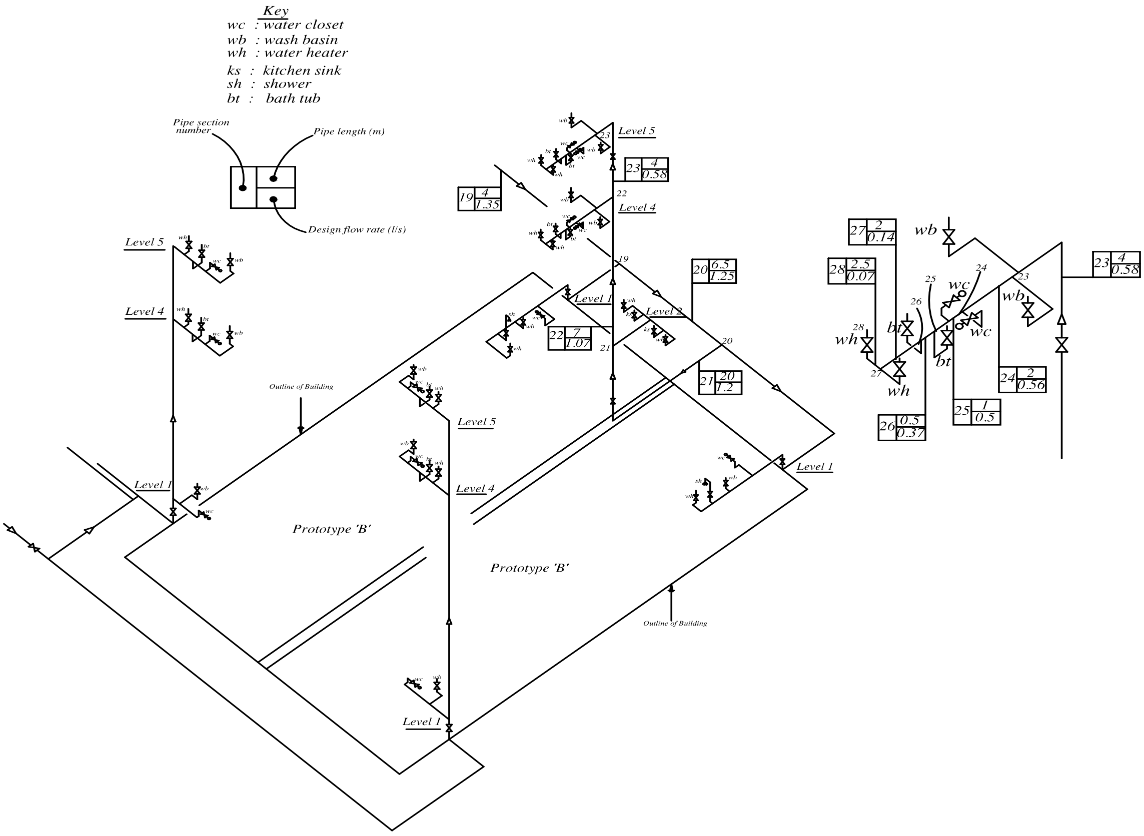

Figure 9. Isometric Sketch of Distribution in Last Building of Prototype B

TABLE V. PIPE SIZING AND CALCULATION OF HEAD LOSS COMPONENTS FOR DISTRIBUTION TO PROTOTYPE A AND B BUILDINGS

Pipe section no. (see Figs 8 and 9)	Loading Units	Design flow (l/s)	Pipe length (m)	Permissible H/L	Diameter (m)	Actual H/L	Frictional head loss h_f (m)	Fittings (Other than reducer)	Reducers (mm x mm)	Loss through fittings, h_p (m)	No. of appliances supplied by pipe section
1	1416.0	8.70	26.0	0.014	100	0.010	0.260	3 elbows, 2 gate valve, 1 tee	-	0.294	396
2	1273.0	8.20	4.0	0.014	100	0.009	0.036	1 gate valve, 1 tee	-	0.125	286
3	1204.0	7.70	22.0	0.014	100	0.007	0.154	1 elbow, 1 tee	-	0.135	270
4	958.0	6.70	4.0	0.014	100	0.006	0.024	1 tee	-	0.074	250
5	712.0	5.30	8.0	0.014	100	0.005	0.040	1 gate valve, 1 tee	-	0.052	192
6	677.5	5.10	5.0	0.014	100	0.004	0.020	1 gate valve, 1 tee	-	0.048	182
7	608.5	4.70	12.0	0.014	75	0.013	0.156	1 tee	100 x 75	0.123	162
8	539.5	4.20	12.0	0.014	75	0.011	0.133	1 tee	-	0.092	142
9	470.5	3.80	14.0	0.014	75	0.010	0.140	1 gate valve, 1 tee	-	0.085	122
10	436.0	3.70	16.0	0.014	75	0.009	0.144	1 elbow, 1 tee	-	0.101	112
11	427.5	3.60	6.5	0.014	75	0.008	0.052	1 elbow, 1 gate valve, 1 tee	-	0.104	108
12	335.5	3.30	6.5	0.014	65	0.015	0.098	1 tee	75 x 65	0.105	88
13	327.0	2.50	4.0	0.014	65	0.011	0.044	1 tee	-	0.058	84
14	308.5	2.40	6.5	0.014	65	0.010	0.065	1 tee	-	0.053	80
15	226.5	2.30	6.5	0.014	65	0.009	0.059	1 tee	-	0.049	60
16	218.0	2.20	4.0	0.014	65	0.008	0.032	1 tee	-	0.045	56
17	209.5	2.10	6.5	0.014	65	0.007	0.046	1 gate valve, 1 tee	-	0.046	52
18	117.5	1.40	6.5	0.014	50	0.013	0.085	1 tee	65 x 50	0.056	32
19	109.0	1.35	4.0	0.014	50	0.012	0.048	1 tee	-	0.048	28
20	100.5	1.25	6.5	0.014	50	0.010	0.065	1 tee	-	0.041	24
21	92.0	1.20	20.0	0.014	50	0.009	0.180	1 elbow, 1 gate valve, 1 tee	-	0.057	20
22	78.0	1.07	7.0	0.014	50	0.008	0.056	1 tee	-	0.030	16
23	31.0	0.58	4.0	0.014	40	0.010	0.040	1 elbow, 1 gate valve, 1 tee	50 x 40	0.034	8
24	28.0	0.56	2.0	0.014	40	0.009	0.018	1 tee	-	0.020	6
25	24.0	0.50	1.0	0.014	40	0.007	0.007	1 tee	-	0.016	4
26	14.0	0.37	0.5	0.014	32	0.012	0.006	1 tee	40 x 32	0.023	3
27	4.0	0.14	2.0	0.014	25	0.007	0.014	1 tee	32 x 25	0.009	2
28	2.0	0.07	2.5	0.014	20	0.008	0.020	1 elbow, 1 gate valve	25 x 20	0.003	1
							2.041			1.926	Cumulative: 396

TABLE VI. SUMMARY OF COMPUTATIONS FOR VALIDATING REGRESSION MODEL EQUATIONS FOR DISTRIBUTION TO GROUPS OF 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.	12 – Unit Residential Housing Estate	$y = 0.007 + 0.003x_1 - 5 \text{ x } 10^{-6}\ x_1{}^2$	Length of Index Pipe Run x_1	181.0m	0.386	0.415	7.0	Equation is Validated
		$y = 0.157 + 0.0024x_2 - 4 \text{ x } 10^{-6}\ x_2{}^2$	Number of Sanitary Appliances x_2	224	0.496	0.415	19.0	"
		$y = 0.097 + 0.106x_3 - 0.006x_3{}^2$	Reservoir Discharge x_3	3.6l/s	0.401	0.415	3.4	"
		$y = 0.157 + 0.04x_4 - 0.001x_4{}^2$	Number of Buildings x_4	12	0.493	0.415	18.8	"
2.	3 Blocks of Terrace Building Each Having 4 Family Units	$y = 0.007 + 0.003x_1 - 5 \text{ x } 10^{-6}\ x_1{}^2$	Length of Index Pipe Run x_1	171.5m	0.374	0.430	13.0	"
		$y = 0.157 + 0.0024x_2 - 4 \text{ x } 10^{-6}\ x_2{}^2$	Number of Sanitary Appliances x_2	230	0.497	0.430	15.0	"
		$y = 0.097 + 0.106x_3 - 0.006x_3{}^2$	Reservoir Discharge x_3	5.2l/s	0.486	0.430	13.0	"
		$y = 0.157 + 0.04x_4 - 0.001x_4{}^2$	Number of Buildings x_4	12	0.493	0.430	14.7	"
3.	8 Units Each of Two Prototype Buildings	$y = 0.007 + 0.003x_1 - 5 \text{ x } 10^{-6}\ x_1{}^2$	Length of Index Pipe Run x_1	219.5m	0.425	0.486	12.6	"
		$y = 0.157 + 0.0024x_2 - 4 \text{ x } 10^{-6}\ x_2{}^2$	Number of Sanitary Appliances x_2	396	0.480	0.486	1.2	"
		$y = 0.097 + 0.106x_3 - 0.006x_3{}^2$	Reservoir Discharge x_3	8.7l/s	0.565	0.486	16.3	"
		$y = 0.157 + 0.04x_4 - 0.001x_4{}^2$	Number of Buildings x_4	16	0.541	0.486	11.3	"

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

IV. SUMMARY AND CONCLUSIONS

The results of analysis of three completed and functional water distribution installations serving groups of buildings were compared with the results obtained from previously obtained regression models, in order to check the validity of the fractions of total head loss due to pipe fittings in index pipe runs, as obtained using the regression equations.

The comparisons as summarized in Table 6 show that all the regression results vary by less than 20% from the case study results; thereby validating the regression models within the range of values of system parameters utilized in obtaining the regression models. These ranges are 108.0m to 304.7m index pipe length, 17 to 272 sanitary appliances, 0.88l/s to 5.60l/s reservoir discharge, and 1 to 16 number of buildings. The validity of the regression equations indicate their usefulness in approximating the total fitting head loss fraction in index runs of water distribution systems serving groups of buildings.

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