Innovative Systems Design and Engineering
ISSN 2222-1727 (Paper) ISSN 2222-2871 (Online)
Vol.5, No.5, 2014

The Head Loss Ratio in Water Distribution: Case Study of a 448-Bed Student Hostel

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Abstract

A case study of a gravity-fed water distribution system for a 448-bed student hostel with a reservoir discharge of 4.4 l/s and an available system pressure head of 4m is presented. It was found that the fraction of the total head loss which constitutes that due to pipe fittings in the first index run is 0.423. In an earlier study, graphs of the fraction against available system head for various discharge rates had been published for other water distribution configurations. The predicted fraction from those graphs being 0.425 (which is close to 0.423) the earlier study is given some validity.

Keywords: Loss through pipe fittings, Reservoir elevation, Design flow rate

1. Introduction

The head loss components in fluid flow systems are the frictional loss and the loss through conduit fittings such as elbows, tees, reducers and valves. It has been observed that the latter loss component, sometimes referred to as minor loss, may in systems which incorporate a substantial multiplicity of fittings appear to be a major loss component.

A common method of calculating the frictional loss component is the use of the Hazen-Williams equation. This equation for plastic pipe material is expressed in terms of head loss per meter pipe run as (Sodiki 2002)

$$h_f / l = 1.1374 \times 10^{-3} \, d^{-4.867} \, q^{1.85} \qquad (1)$$

where h_f = frictional head loss

l = pipe length (m)

d = pipe diameter (m)

q = flow rate (m^3/s)

Eqn. 1 is usually expressed in graphical form such as that in Fig. 1 (Institute of Plumbing 1977); and such graphs are more commonly used in practice as values can be retrieved quicker from them than from Eqn. 1. Thus, with a knowledge of a maximum permissible head loss per meter (which should not be exceeded) and the required water flow rate, a pipe size can easily be selected from Fig. 1.

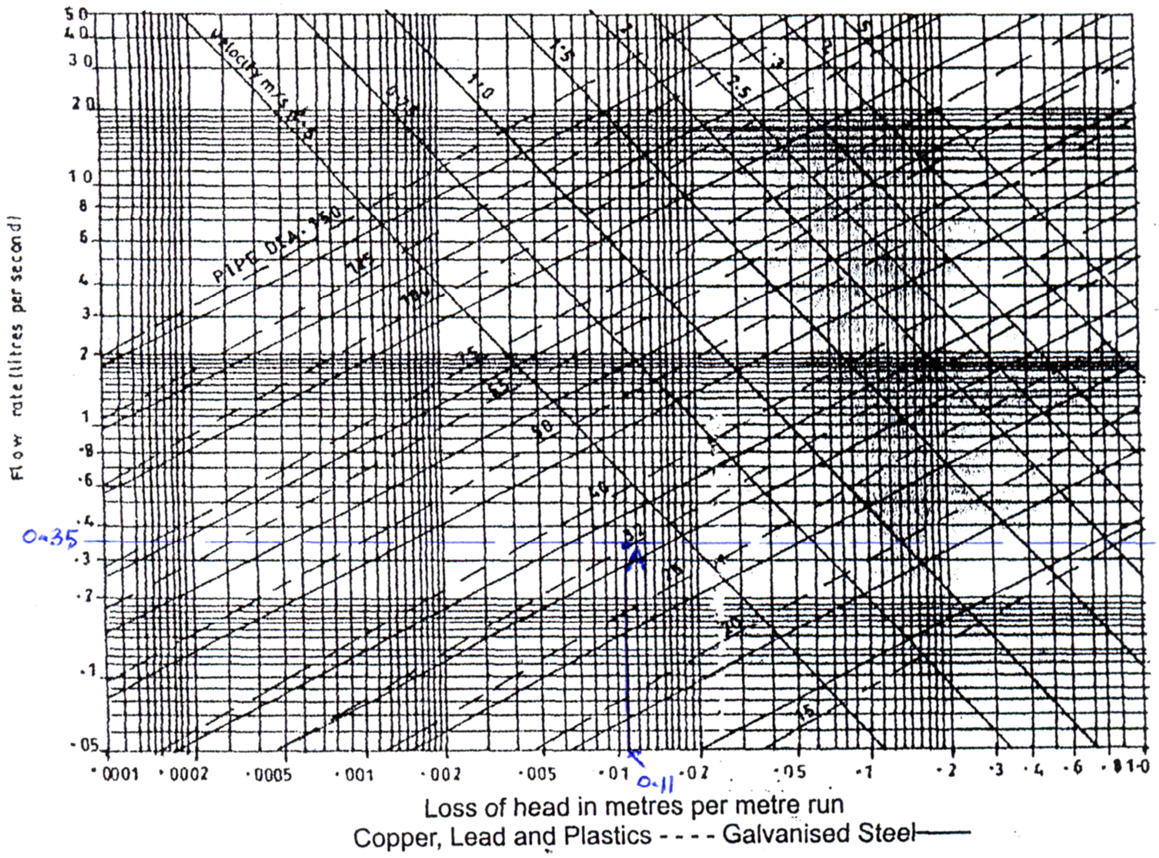

Fig. 1: Pipe Sizing Graph (Institute of Plumbing 1977)

The head loss through a conduit fitting h_p is usually calculated using a head loss coefficient k in the D'Arcy – Weisbach equation in the form

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

Expressed in terms of flow rate q and diameter d (which are more readily determinable than v), Eqn. 2 can be expressed as (Sodiki 2003).

$$h_p = 0.08256kd^{-4}q^2 \qquad (3)$$

In determining head losses in fluid distribution systems for the purpose of determining a suitable source pressure (such as that at an elevated reservoir, pump or compressor), a critical consideration is to ensure that there remains a positive pressure at the farthest supply terminal after the losses have been deducted (from the available source pressure). The conduit run up to the farthest supply terminal is referred to as the first index run. It is the end of this run that is most likely to be starved of water in the event of reduced water distribution system pressure. If the water flow rate and pressure at this end are calculated to be adequate, then all other points within the system would receive adequate supply.

In many practical situations the fitting loss component for the first index run is approximated as a fraction of the frictional component. For instance, Church (1979) had suggested a 150% multiplication (i.e. a 50% addition) of the measured length of the first index run to account for the losses due to all installed fittings in the pipe run, in a procedure for selecting hot water circulating pumps.

Also, in considering water distribution systems in buildings, Barry (1984) had stated : "it is necessary to make an estimate of the likely length of pipe whose resistance to flow is equivalent to the resistance of the pipe fittings. This is usually taken as a percentage of the actual pipe length. The percentage may vary from 25 to over 100. With experience in pipe sizing, this assumed percentage will approach a fair degree of accuracy".

In like manner, while analyzing head losses in water distribution systems, Tiscala U.K. Ltd (2012) had stated: "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)".

In the foregoing instances, the stipulated approximations for estimating losses through pipe fittings have no clear statistical basis. However, a recent study (Sodiki 2014) had developed regression models for estimating the fraction of the total head loss which is due to flow through pipe fittings for some water distribution systems in buildings. Also, the effect of varying the available distribution source pressure (by varying the elevation of the water reservoir) on the fraction of loss due to fittings had been studied (Sodiki 2013).

In those studies, common configurations of water distribution systems were utilized to generate data of frictional loss and loss through fittings; adopting the estimating procedure explained earlier (i.e. the graphical method for frictional losses and the use of loss coefficient k for fitting losses). The generated data were then used to carry out regression analyses, and to study the effect of variation of available system pressure on the head loss components using 'Excel' plots.

This paper presents a case study of water distribution in a 448-bed student hostel building. The frictional and fitting loss components in the first index pipe run are calculated; hence the fraction of head loss representing that through fittings so obtained is compared with that obtained from the 'Excel' plots obtained in the earlier study. This serves to check the agreement with the earlier work.

2. Distribution System Description

The floor plans of the hostel block showing the water distribution layout are in Figs. 2 to 4, and an isometric sketch of the layout is shown in Fig. 5. Water is distributed by gravity from a set of roof-mounted tanks.

From Figs. 2 and 5, the pipe run serving the front wing from the reservoir (i.e. pipe run from A, B, C, up to P) appears to be longest run (thus being the first index run) in the distribution system. In Fig. 5 the pipe sections in the first index run are designated by means of boxes such that the number on the left of the box is the pipe section number, that on the top right is the pipe length (in m) while that on the bottom right is the design flow (in l/s). The last few sections of the first index run are shown enlarged in Fig. 5b to achieve clarity.

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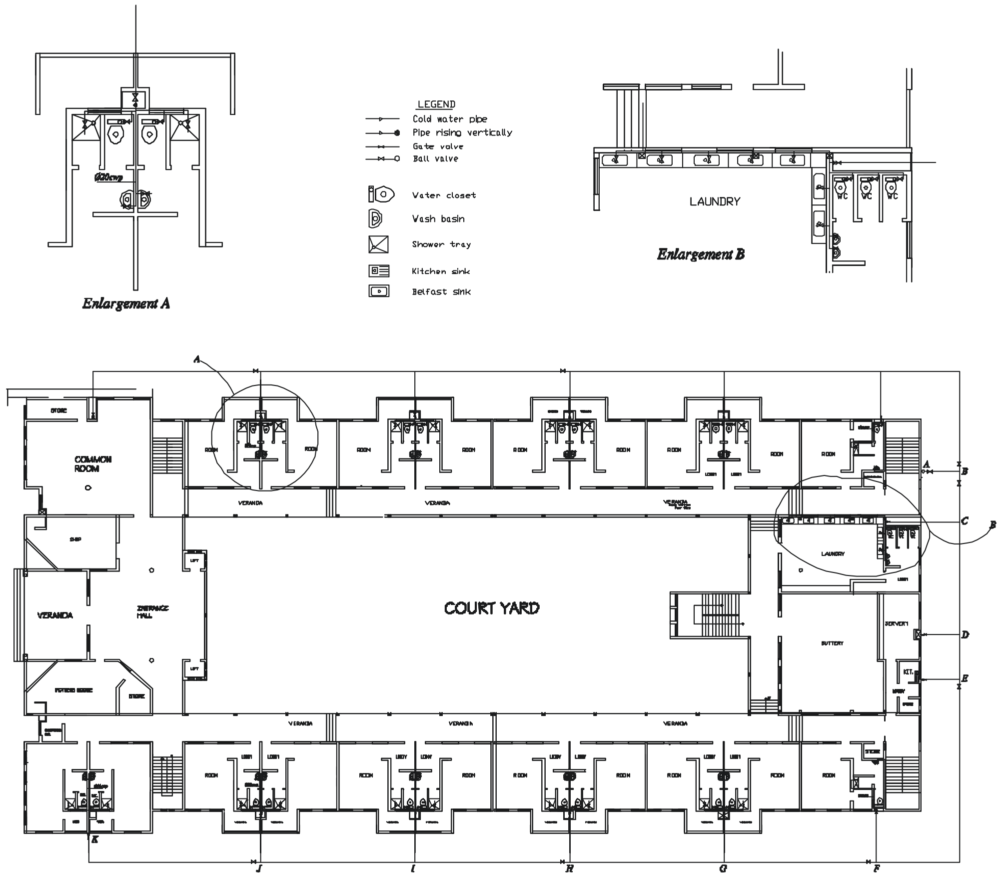
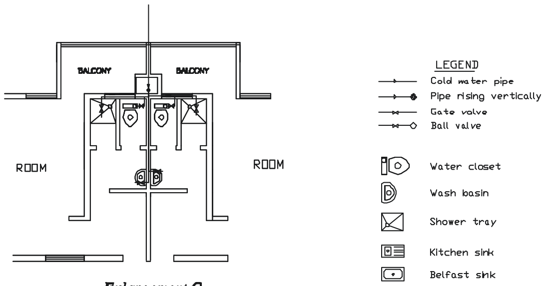


Fig.2: Ground Floor Plan



Enlargement C

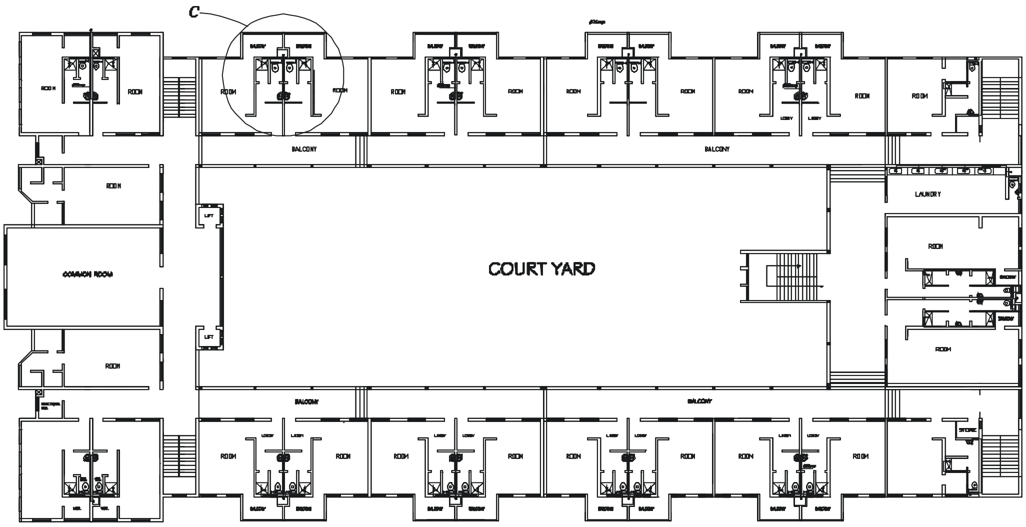


Fig 3: First Floor Plan

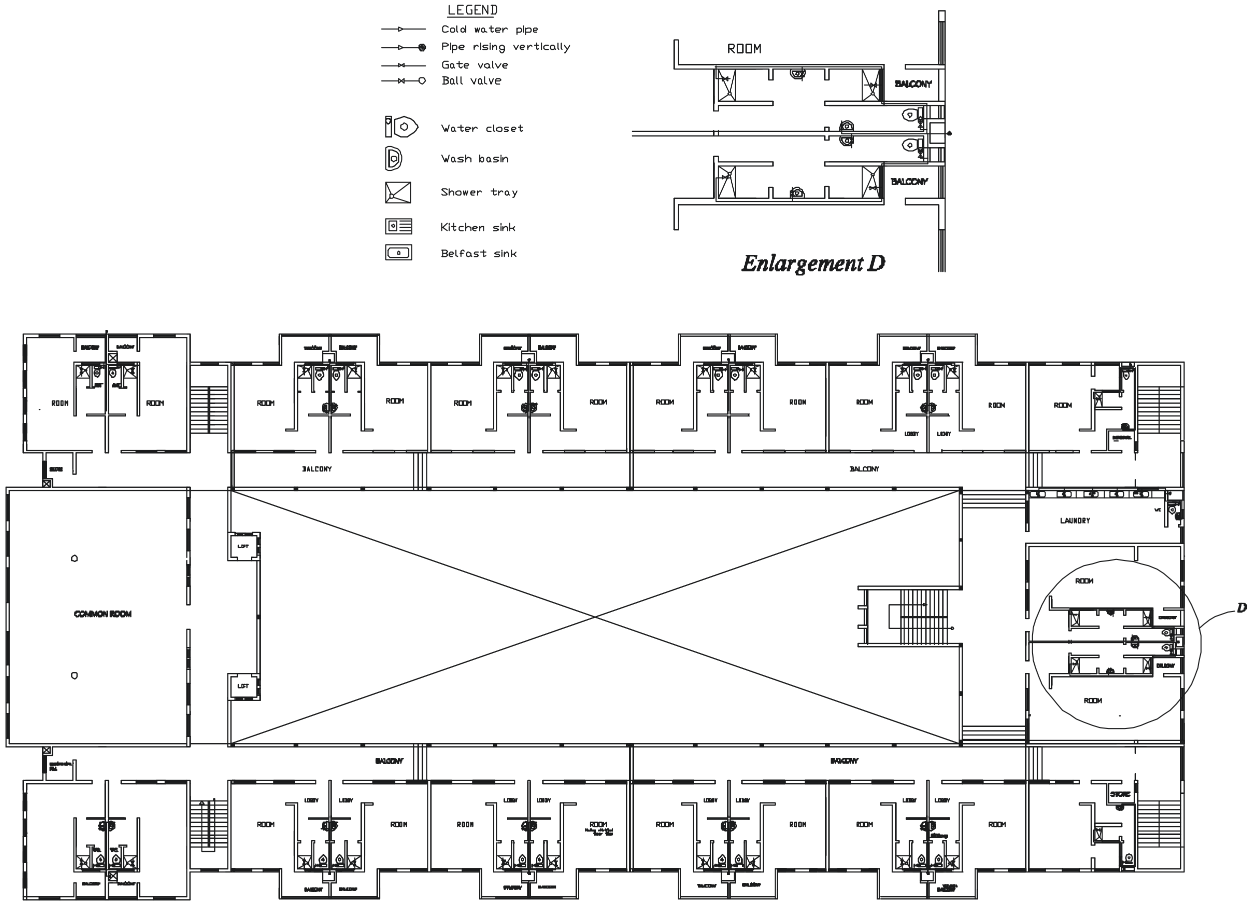


Fig.4: Second Floor Plan

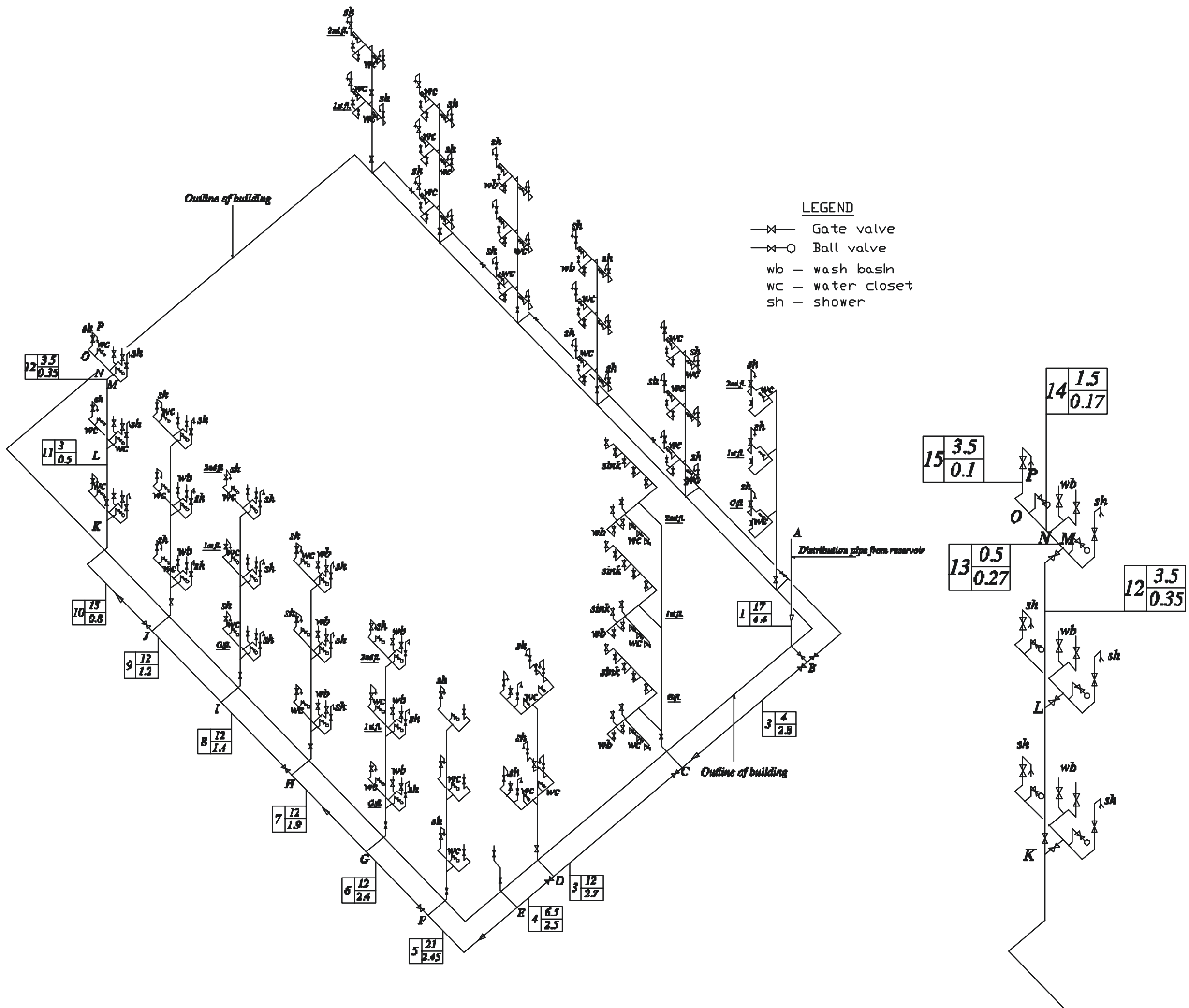


Fig 5a: Complete Distribution System

Fig 5: Isometric Drawing Showing Cold Water Distribution

Fig. 5b: Enlargement of Last Few Pipe Sections

3. Distribution Layout Planning, Pipe Sizing and Calculation of Head Losses

In order to reduce pressure losses in the system, the distribution layout is made as simple as possible with appropriate pipe fittings provided wherever needed.

To account for the non-simultaneous use of all the installed sanitary appliances, fixture loading units are given as (Institute of Plumbing 1977) 2 for a water closet, 1.5 for a wash basin, 3 for a shower and 3 to 5 for a sink (an average of 4 being used in this study). Water flow rates in different pipe sections are obtained from the graph of cumulative loading units versus flow rates of Fig. 6 (Institute of Plumbing 1977). For loading units less than 10 which is the minimum value displayed in Fig. 6, linear extrapolations are used to obtain the corresponding flow rates.

The pipe sizing calculations for the first index run of pipe (i.e. from A, B, C up to P) designated as pipe sections 1, 2, 3, to 15 are summarized in Table 1. Now, chosen height of the reservoir outlet connection above the highest fixture outlet (i.e. the shower in pipe section 15) is the available pressure head H ; and in this study is taken as 4 m. Measured length of the first index run $L = 206.5m$. Thus, the permissible maximum rate of head loss per metre run is

$$\frac{H}{L} = \frac{4}{206.5} = 0.019$$

This H/L value is used in conjunction with the sectional flow rates to obtain pipe sizes from the graph of Fig. 1. At the intersections of the lines of flow rate and pipe diameter, the actual head losses H/L are read off from the horizontal axis. Multiplying the actual H/L value with the sectional length gives the frictional loss for each section.

For instance, for pipe section 12 having a flow rate of $0.35\, l/s$ and with the maximum permissible H/L of 0.019, a 32 mm pipe size is selected and the actual H/L is 0.011 (point A in Fig. 1). As the measured length of this section is 3.5 m, the frictional loss is 0.011 x 3.5m = 0.039 m.

The losses through pipe fittings are obtained from Eqn. 3, using the K -values of 0.25 for gate valves, 2.0 for tees and 0.75 for elbows (Giles 1977). To obtain K -values for reducers, the ratio of upstream diameter d_1 to downstream diameter d_2 are utilized in Table 2 (Giles 1977). In pipe section 12, for instance, there are one gate valve, one tee, one elbow, and one 40 mm x 32 mm reducer. Then, h_p for this section is 0.08256 x (0.25 + 2 + 0.75 + 0.1025) x 0.032^{-4} x $(0.35 \times 10^{-3})^2$ = 0.030 m, noting that for the reducer, d_1/d_2 = 1.25 with a corresponding K -value of 0.1025 obtained by interpolation in Table 2.

From Table 1, the total frictional loss in the first index run is 1.103 m while the total loss through pipe fittings is 0.808m; resulting in a total of 1.911 m and a fraction of loss through fittings of 0.423. The frictional loss fraction is 0.577.

Table 1: Pipe Sizing and Calculation of Head Loss Components

Pipe section no.	Loading 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)
1	398.5	4.40	17.0	0.019	75	0.007	0.119	1 gate valve, 1 tee, 2 elbows	-	0.189
2	288.0	2.80	4.0	0.019	65	0.013	0.052	1 gate valve, 1 tee	75 x 65	0.084
3	262.5	2.70	12.0	0.019	65	0.012	0.144	1 gate valve, 1 tee	-	0.075
4	218.5	2.50	6.5	0.019	65	0.010	0.065	1 gate valve, 1 tee,	-	0.065
5	214.5	2.45	21.0	0.019	65	0.009	0.189	1 tee, 1 elbow	-	0.076
6	195.0	2.40	12.0	0.019	65	0.008	0.096	1 gate valve, 1 tee	-	0.060
7	156.0	1.90	12.0	0.019	65	0.004	0.048	1 tee	-	0.033
8	117.0	1.40	12.0	0.019	50	0.012	0.144	1 gate valve, 1 tee,	65 x 50	0.061
9	78.0	1.20	12.0	0.019	50	0.009	0.048	1 gate valve, 1 tee,	-	0.043
10	39.0	0.80	15.0	0.019	50	0.004	0.060	1 gate valve, 1 tee, 1 elbow	-	0.025
11	26.0	0.50	3.0	0.019	40	0.009	0.027	1 gate valve, 1 tee	50 x 40	0.017
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
13	8.0	0.27	0.5	0.019	32	0.007	0.004	1 tee	-	0.011
14	5.0	0.17	1.5	0.019	25	0.010	0.015	1 tee	32 x 25	0.013
15	3.0	0.10	3.5	0.019	20	0.015	0.053	1 gate valve, 4 elbows	25 x 20	0.026
			206.5				1.103			0.808

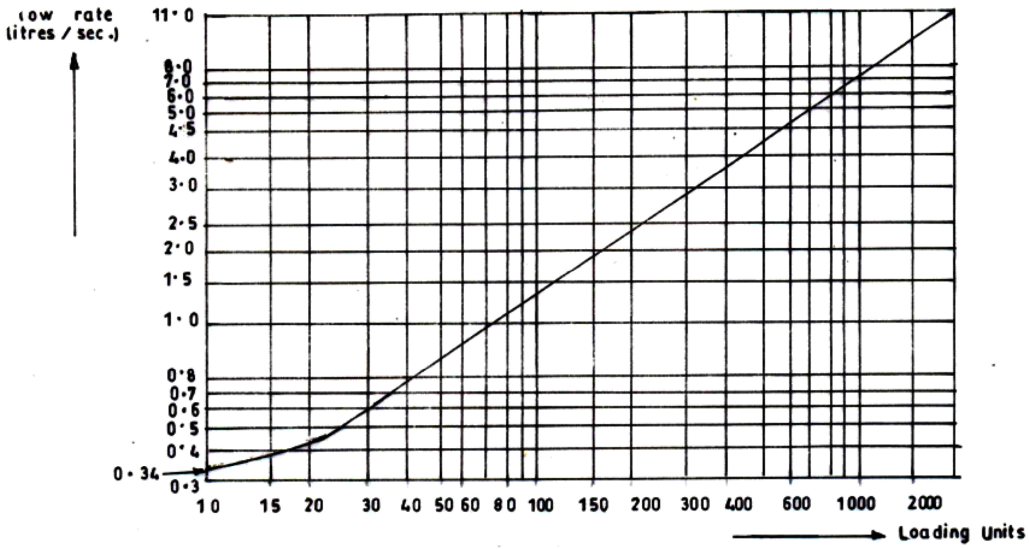


Fig. 6: Graph of Loading Unit Versus Flow Rate (Institute of Plumbing 1977)

Table 2: 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

4. Discussion of Results

With the available distribution system head of 4 m and a total head loss of 1.911m in the first index run, there remains a head of 4 m – 1911 m = 2.089 m. The remaining of a positive head indicates that water will flow to all terminal points in the distribution system; and so the chosen reservoir elevation is adequate. If, on the other hand, a negative (or too low positive) head remained from the calculations, the reservoir elevation would need to be increased and the pipe sizing calculations repeated until a comfortable positive head remained at end of the first index run.

An earlier study (Sodiki 2013) had graphically shown the variation of the ratio of loss through pipe fittings to total loss with available distribution system head, for varying reservoir discharge rates. One result of that study (which corresponds to the present case study) is shown in Fig. 7. Fig 7 is an 'Excel' plot for a reservoir discharge of 4.40 l/s and, from it, at an available system head of 4 m, a ratio of loss through fittings to total loss of 0.425 is obtained. This ratio is quite close to the value of 0.423 of the present case study.

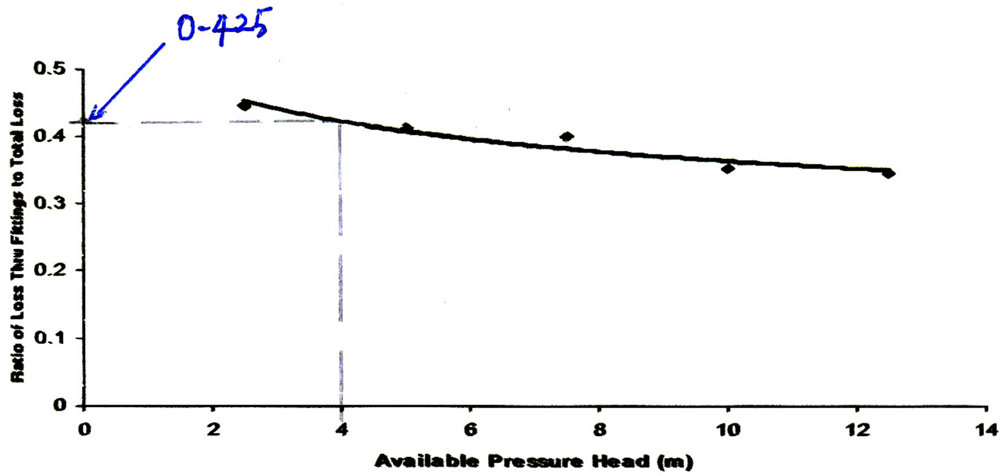


Fig. 7: Variation of Fitting Loss Fraction with Available Head for Distribution with 4.40 L/s Flow Rate (Sodiki 2013)

5. Conclusion

The methods applied for pipe sizing and calculation of head loss components in this case study are useful for other water distribution systems in determining the adequacy of reservoir elevations; bearing in mind also that an unnecessarily high elevation would require a higher cost due to the higher cost of construction of the supporting structure and the higher rating of the lift pump.

The fraction of the total head loss which constitutes that through fittings as obtained from this study being close to that obtained in an earlier published work, gives some validity of the results of that work.

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