Optimal Design of Water Plumbing System in Multistoreyed Building

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Abstract- **Multistoreyed buildings are inevitable in today's modern living. For plumbing purposes, the term "multi-storey" is applied to buildings that are too tall to be supplied throughout by the normal pressure in public water mains. Water main supply pressure of 8-12 meter (25-40 feet) can supply a typical two-storey building, but higher buildings may need pressure booster systems. The main aim of the study is to develop optimization model for designing down feed piping system in multistoreyed building by minimizing the cost of piping. The specific objectives of this study are: To develop linear programming-based methodology for the design of water plumbing system in multistoreyed building. To demonstrate the applicability of the developed optimal design method for example problem. To compare the performance of the developed optimal design method with traditional method of design.**

Keywords- Design of plumbing, Investment cost, Rain water, Water supply, Waste water.

I. INTRODUCTION

In recent years, the rapid development of the economy, whether it is urban or township, the degree of housing community is getting higher and higher, people's requirements for the water supply and drainage function of the building are constantly improving. In this paper, the seven-storey building in a certain district is taken as the research object, and the design analysis is carried out according to the relevant data of the building.[1]

Plumbing is a general term which indicates the practice, materials and fixtures used in the installation and maintenance of all piping, fixtures, appliances, and other appurtenance used in the connections both the public and private water supply system, within or adjacent to or any building or any connection with any point of public disposal. The entire system of piping, fixtures, appliances, etc. used in providing water supply and drainage to a building is, therefore it is called a plumbing system.[2]

The distribution of water within the building from the city mains or the other sources such as ground water can be obtained by several piping systems. Each method has its own merits and demerits depending upon the local conditions. Such piping systems must, however, is designed to provide uniform flow and pressure in all floors and places within certain practical limitations.[3]

To meet the water requirement during non-supply hours, the piping system using overhead tank is used where water is stored in overhead tanks placed on the terrace, which are filled with the direct connections from the mains.[4]

Traditionally the pipes are designed by balancing the frictional head loss with the potential energy to meet the pressure head and discharge requirements. By the traditional method of design, we may not get the result in the minimum cost of the piping system. Therefore, we can use optimization methods for minimizing the cost of the piping system satisfying the pressure head and discharge requirements.[5]

The optimality of a design depends on the model and is assessed with respect to a criterion, specifying an appropriate model. The optimal solution always means minimum cost of network. The word "minimum" is only relative. With different criteria or objection functions; different values for "minimum cost" can be obtained for the same system.[6]

II. RESEARCH METHODOLOGY

To develop a linear programming for the design of down feed piping system in a multistoried building. To demonstrate the applicability of the developed optimal design method for example problems. To compare the performance of the developed optimal design method with the traditional method of design. Compare the developed optimal design method with the traditional method of design.

The model selects the design pipe sizes for the main (downfeed) as well as the branch lines in the buildings from the available diameters in the market. The decision variables of the optimization model will be the lengths of the different available diameters for pipes in different

floors. The constraints for recommended minimum and maximum values of velocity in the pipes will also be imposed in the model. LINGO 19.0 will be used to solve the linear programming-based model. Different equations are available for computing frictional head loss such as due to Darcy-Weisbach, Hazen-Williams, Scoby etc. We use Darcy- Weisbach and Hazen-William's formulae for this study.

III. RESULTS AND DISCUSSION

The traditional and optimal methods for design of piping systems in buildings were presented. The design requirements for piping system. The application of design methods is illustrated through design examples. The solution results to calculate the pipe diameters by both optimization and traditional methods are presented and discussed. Further, the optimal design method is also applied to see the effect of number of hydraulic zones in tall buildings in total cost of the piping system.

1. Water supply by underground overhead tank:
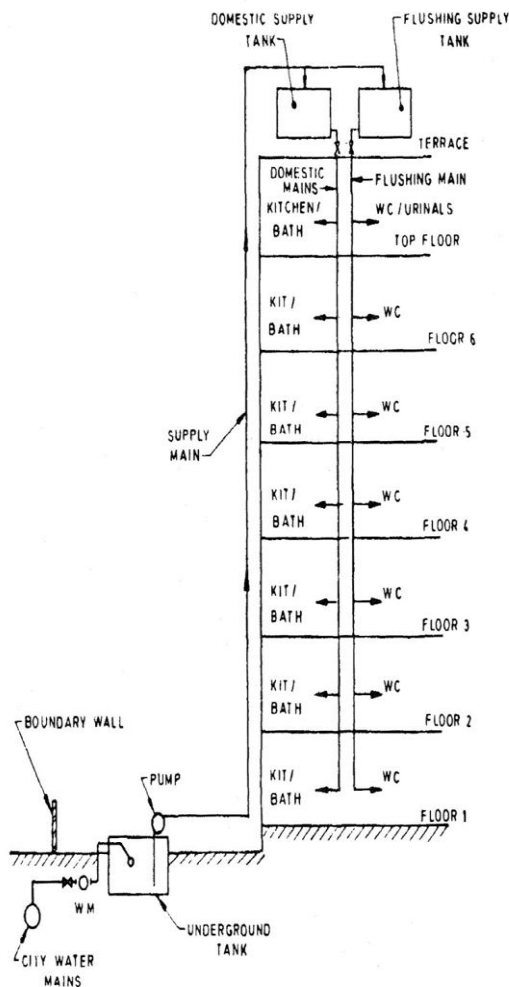
Fig 1. Water supply.

2. Flow chart for design of piping system by optimization method:
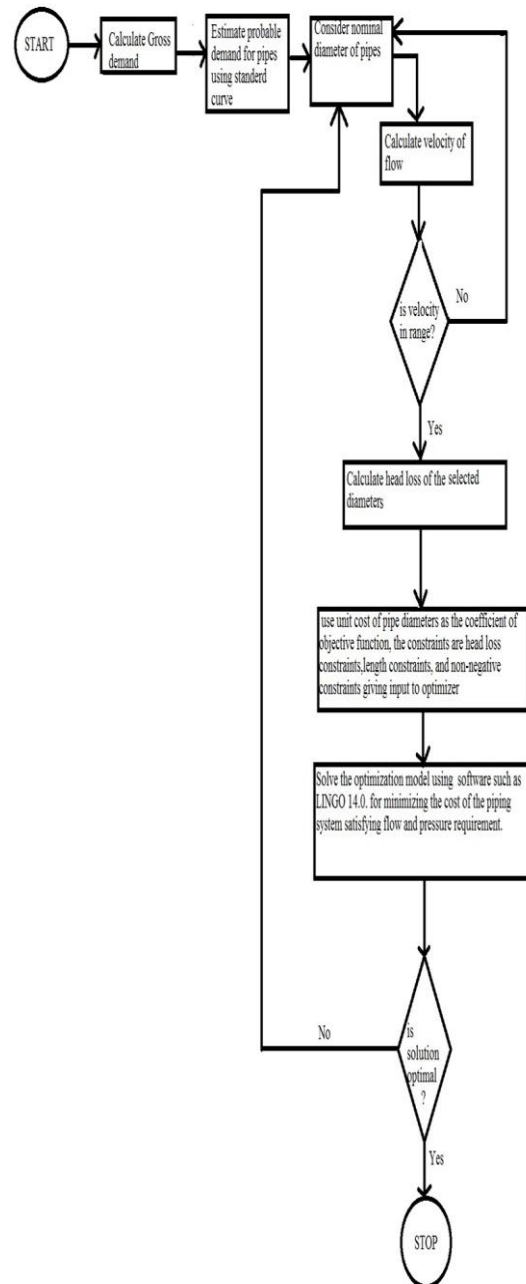
Fig 2. Flow Chart.

IV. TRADITIONAL DESIGN

By trial-and-error method, selection of pipe diameters was made by considering the energy head loss in each floor or sector as nearly equal to the available static head at that point as given in Table 1.1. The cost of piping system is then calculated according to the selected diameters and is given in Table 1.1. From Table 1.1 it can be seen that the cost of the piping system designed by traditional method using Darcy-Weisbach Formula is Rs.14902.65.

The diameters were also selected by using Hazen-William equation for head loss calculation. The design diameters of pipes with the cost of the system are given in Table 1.1. The cost of the piping system using HazenWilliam Equation is Rs.15224.85.

Table 1. The design diameters of pipes with the cost of the system

Storeys	Nominal Diameter (mm)	Internal Diameter (mm)	Cumulative Head Loss (m)	Static head available (m)
7th storey				
Main pipe	40	42.5	.522	
Branch pipe of first flat	20	21.3	.2713	
	20	21.3	.5426	
	20	21.3	.3488	
	20	21.3	.0627	
Branch pipe of second flat	Four pipes of 20mm diameter	Four pipes of 21.3mm diameter	1.225	
			2.972m~3m	3m
6th storey				
Main pipe	40	42.5	.6654	
Branch pipe of first flat	Four pipes of 20mm diameter	Four pipes of 21.3mm diameter	1.225	
Branch pipe of second flat	Four pipes of 20mm diameter	Four pipes of 21.3mm diameter	1.225	
			6.087~6 m	6m
5th storey				
Main pipe	40	42.5	.4238	
Branch pipe of first flat	Four pipes of 20mm diameter	Four pipes of 21.3mm diameter	1.225	
Branch pipe of second flat	Four pipes of 20mm diameter	Four pipes of 21.3mm diameter	1.225	
			8.96~9m	9m
4th storey				
Main pipe	25	26.9	1.845	
Branch pipe of first flat	Four pipes of 20mm diameter	Four pipes of 21.3mm diameter	1.225	
			12.03~12 m	12m
3rd storey				
Main pipe	25	26.9	1.458	
			13.488m	15m (friction loss is ignored)
2nd storey				
Main pipe	20	21.3	21.496m	
			15.637m	18m (friction loss is ignored)
Ground floor				
Main pipe	20	21.3	.96	
			16.597m	21m (friction loss is ignored)

1. Pipe Sizing in a 7 storey Building:
To test the performance of the developed model, it is necessary to carryout sensitivity analysis. The effect of number of hydraulic zones on optimal cost is investigated with the help of an example of water supply piping system in a 7-storey building.

Table 2. Pipe diameters by traditional method using Darcy- Weisbach equation.

S. N	Storey	Optimal length (m)	Designed diameter (mm)	Design flow (1/s)	Objective value
1	7th	5	40	1.3	14902.65
2	6th	3	40	1.25	
3	5th	3	40	1	
4	4th	3	25	.9	
5	3rd	3	25	.8	
6	2nd	3	20	.6	
7	1st	3	20	.4	

Table 3. Pipe diameters by traditional method using Hazen-William equation.

S.N	Storey	Optimal length (m)	Designed diameter (mm)	Design flow rate (1/s)	Objective value
1	7th	5	50	1.3	15224.85
2	6th	3	40	1.25	
3	5th	3	40	1	
4	4th	3	32	.9	
5	3rd	3	25	.8	
6	2nd	3	20	.6	
7	1st	3	20	.4	

2. Preliminary Computation:

First, the linear programming-based optimization method developed in this study is used to compute the optimal diameter of downfeed pipes. Then, the traditional method of pipeline design is used to determine the diameters of downfeed pipe in different floors of the building. First the flow rates were estimated then the energy head loss in downfeed pipes as well as branch pipes were computed by both Darcy-Weisbach and Hazen William's equations.

Table 4. Unit cost of available GI pipe sizes.

S.No.	Pipe diameter (mm)	Cost per unit length (Rs/m)
1	15	79.00
2	20	102.00
3	25	153.00
4	32	193.00
5	40	222.00
6	50	312.00
7	65	401.00
8	80	515.00
9	100	757.00
10	125	1014.00
11	150	1209.00

Table 5. Fixtures and fixture units.

Type of fixture	Fixture units
Water closet	1
Water basin	1
Bath tub with shower	4
Kitchen sink	2
Total	8

The frictional head loss of branch lines was considered from top floor to fourth floor and one part of third floor and for lower floors, it was ignored. Considering the nominal diameter of downfeed pipes in mm as 50, 40, 32, 25, 20, 15, the internal diameters were calculated by using outside diameters and thickness values from IS 1239(Part 1)-2004.

Table 6. Calculation of internal diameter.

Nominal diameter (mm)	Calculation for internal diameter	Internal diameter (mm)
50	59.7- (2*3.6)	52.5
40	47.9- (2*3.2)	41.5
32	42- (2*3.2)	35.6
25	33.3- (2*3.2)	26.9
20	26.5- (2*2.6)	21.3
15	21- (2*2.6)	15.8

Table 7. Velocity of water flow in pipes for topmost floor.

Nominal diameter (mm)	Internal diameter (mm)	Discharge (m^3/s)	Velocity (m/s)
50	52.5	.0013	.6
40	41.5	.0013	.962
32	35.6	.0013	1.3068
25	26.9	.0013	2.288
20	21.3	.0013	3.6505
15	15.8	.0013	6.634

Similarly for other floors i.e., from 6th to ground floor, diameters were considered in the same way as above. Energy head loss values were calculated by Darcy-Wiesbech formula as given in Table 1.8. Friction factor values were calculated using equation 3.2. Head Loss through branch pipes should be included for the proper design of piping system in building.
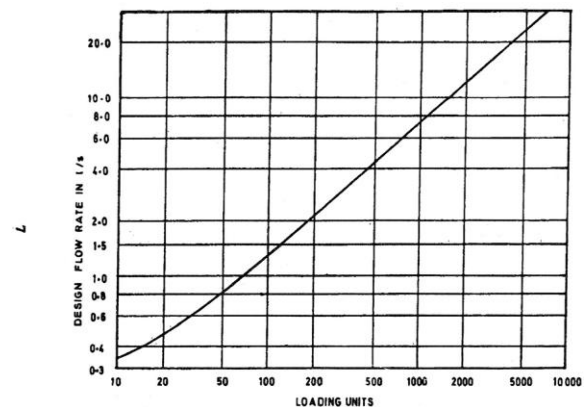

Fig 3. Friction factor values.

The diameter assumed for calculation was 20mm for best results. Pipe markings are as 8, 9, 10, and 11. The probable demands determined from and head loss values are shown in Table 1.9. Then total head loss through branch pipes in one flat of a floor was calculated as 1.2255 m. This head loss is for one flat, there are two flats in every floor so the total head loss in each floor is 2×1.2255= 2.45 m.

The head loss calculated above is in m/m, head loss in meters is HL× (L+Leq) m as given in Table 1.10.

Energy head loss was also calculated by Hazen-Williams Formula. The values thus calculated are given in Table 1.11. The solution by optimal and traditional design methods are presented in the following subsections.

V. OPTIMAL DESIGN

The example was solved as a linear programming problem formulated according to Equations 3.9 to 3.12 using LINGO 19.0. The head losses were calculated by Darcy-Weisbach equation. The optimization model for this problem is as:

$Minimize[Z]$=312*x1+222*x2+193*x3+312*x4+222*x5+193*x6+222*x7+193*x8+153*x9+2 22*x10+193*x11+153*x12+222*x13+193*x14+153*x15+193*x16+153*x17+102*x18+153*x 19+102*x20+10930.5;

Constraints for the optimization model are:
23-(.02*x1+.06*x2+.123*x3)-2.45>=p1;
p1>=20;
x1+x2+x3=5;
p1-(.03*x4+.084*x5+.16*x6)-2.45>=p2;

Table 8. Energy head loss for downfeed pipes in m/m using Darcy-Weisbach formula.

Storey	Nominal diameter (mm)	Internal diameter (mm)	Discharge (m³/s)	Velocity (m/s)	Reynolds number	Friction factor	Length	Head loss (m/m)
7th	50	52.5	0.0013	0.60088	31546.67	0.0299	5	0.020433
	40	41.5	0.0013	0.96164	39908.43	0.0306	5	0.060314
	32	35.6	0.0013	1.30681	46522.47	0.0313	5	0.123782
6th	50	52.5	0.00125	0.57777	30333.33	0.0300	3	0.030183
	40	41.5	0.00125	0.92466	38373.49	0.0307	3	0.084659
	32	35.6	0.00125	1.25654	44733.15	0.0314	3	0.1678
5th	40	41.5	0.001	0.73973	30698.8	0.0313	5	0.041201
	32	35.6	0.001	1.00523	35786.52	0.0319	5	0.083405
	25	26.9	0.001	1.76061	47360.59	0.0335	5	0.311105
4th	40	41.5	0.0009	0.6657	27628.92	0.0316	3	0.044409
	32	35.6	0.0009	0.90471	32207.87	0.0322	3	0.087933
	25	26.9	0.0009	1.58455	42624.54	0.0377	3	0.314445
3rd	32	35.6	0.0008	0.80419	28629.21	0.0325	3	0.069794
	25	26.9	0.0008	1.40849	35887.32	0.0339	3	0.249378
2nd	32	32.6	0.0006	0.60314	21471.91	0.0335	3	0.039765
	25	26.9	0.0006	1.05637	28416.36	0.0347	3	0.141775
	20	21.3	0.0004	1.68485	35887.32	0.0362	3	0.420101

1st	25	26.9	0.0004	0.70424	18944.24	0.0360	3	0.06424
	20	21.3	0.0004	1.1232	23924.88	0.0372	3	0.189732
	15	15.8	0.0004	2.04133	32253.16	0.0395	3	0.787778

Table 9. Head loss in branch pipes in meter.

Pipe no.	Nominal diameter (mm)	Internal diameter (mm)	Discharge in m³/s	Length (m)	Head loss (m)
8	20	21.3	.00012	1.5	0.627
9	20	21.3	0.00024	3	.3488
10	20	21.3	0.0003	3	.523
11	20	21.3	0.0003	1.5	.2713

$$p2 \geq 17;$$
$$x4+x5+x6=3;$$
$$p2-(.054*x7+.108*x8+.387*x9)-2.45 \geq p3;$$
$$p3 \geq 14;51$$
$$x7+x8+x9=3;$$
$$p3-(.044*x10+.087*x11+.314*x12)-1.225 \geq p4;$$
$$p4 \geq 11;$$
$$x10+x11+x12=3;$$
$$p4-(.035*x13+.069*x14+.249*x15) \geq p5;$$
$$p5 \geq 8;$$
$$x13+x14+x15=3;$$
$$p5-(.039*x16+.142*x17+.42*x18) \geq p6;$$
$$p6 \geq 5;$$

Table 1.10 Head loss of downfeed pipe in meters

storey	Nominal diameter (mm)	Internal diameter (mm)	Equivalent length for 90 elbow (mm)	Equivalent length for tee (m)	Total equivalent length, Leq (m)	L+Leq (m)	Head loss (m)
7th	50	52.5	1.579786	3.159572	4.739359	9.739	0.1990
	40	41.5	1.21898	2.47396	3.65694	8.656	0.52213
	32	35.6	1.021956	2.043929	3.065894	8.06	0.99841
6th	50	52.5	1.573038	3.146075	6.29215	9.292	0.28046
	40	41.5	1.212034	2.430068	4.860137	7.860	0.66543
	32	35.6	1.019257	2.430068	4.077028	7.077	1.18752
5th	40	41.5	1.190824	2.038514	4.763296	7.763	0.42389
	32	35.6	1.002509	2.002018	4.010035	7.010	0.75815
	25	26.9	1.511519	3.023038	6.046076	9.046	0.14340
4th	40	41.5	1.178329	2.356658	4.713315	7.71	0.34254
	32	35.6	0.993774	1.987584	3.975097	6.975	0.61334
	25	26.9	0.717344	1.434689	2.869377	5.869	1.84559
3rd	32	35.6	0.983356	1.966713	3.933425	6.933	0.48391
	25	26.9	0.71214	1.424279	2.848558	5.848	1.45850

Storey	Diameter						
2nd	32	35.6	0.954918	1.909835	3.933425	6.819	0.27118
	25	26.9	0.697601	1.395201	2.848558	5.790	0.82093
	20	21.3	0.529226	1.058452	3.81967	5.116	2.14961
1st	25	26.9	0.672287	1.344574	2.790402	5.689	0.36547
	20	21.3	0515016	1.030033	2.116904	5.060	0.96005
	15	15.8	0.359231	0.718462	2.686149	4.436	3.49531

Table 11. Head loss by Hazen-William formula.

Storey	Length (m)	Diameter (mm)	Head loss (m/m)	Head loss (m)
7th	5	5.25		
	5	4.15	0.026552	0.132759
	5	3.56	0.077663	0.388316
6th	3	5.25	0.15718	0.785902
	3	4.15	0.020417	0.061251
	3	3.56	0.052292	0.156877
5th	3	4.15	0.096567	0.289701
	3	3.56	0.033467	0.100401
	3	2.69	0.061803	0.185409
4th	3	4.15	0.189583	0.56875
	3	3.56	0.05006	0.081325
	3	2.69	0.153562	0.150181
3rd	3	4.15	0.021419	0.460687
	3	3.56	0.039554	0.064257
	3	2.69	0.121333	0.118662
2nd	3	3.56	0.022249	0.364
	3	2.69	0.06825	0.066747
	3	2.13	0.173617	0.20475
1st	3	2.69	0.030333	0.520852
	3	2.13	0.077163	0.091
	3	1.58	0.254859	0.23149

x16+x17+x18=3;
p6-(.064*x19+.189*x20)>=p7;
p7>=2;
x19+x20=3

The above model was solved by LINGO 19.0. The results for the developed model are given in Table 4.10. It can be seen from Table 1.12 that the optimal cost of the piping system from this developed model is Rs. 14570.98.

Then the optimization model was reformulated for the example problem using head losses calculated from Hazen- Williams's formula.

The optimization model is presented as:
$Minimize[Z]=312*x1+222*x2+193*x3+312*x4+222*x5+193*x6+222*x7+193*x8+153*x9+222*x10+193*x11+153*x12+222*x13+193*x14+153*x15+193*x16+153*x17+102*x18+153*x19+102*x20+10750.33$

Constraints for the above model are as below:
23-(.026*x1+.077*x2+.157*x3)-2.67>=p1;
p1>=20;
x1+x2+x3=5;
p1-(.02*x4+.052*x5+.096*x6)-2.67>=p2;
p2>=17;
x4+x5+x6=3;
p2-(.033*x7+.062*x8+.189*x9)-2.67>=p3;
p3>=14;
x7+x8+x9=3;
p3-(.027*x10+.05*x11+.153*x12)-2.67>=p4;
p4>=11;
x10+x11+x12=3;
p4-(.021*x13+.039*x14+.121*x15)-1.335>=p5;
p5>=8;

Table 12. Optimal diameters using Darcy-Weisbach equation.

S.N	Storey	Optimal length (m)	Optimal diameter (mm)	Design flow rate (1/s)	Objective value
1	7th	1.0317	40	1.3	14570.98
		3.9683	32		
2	6th	3	32	1.25	
3	5th	3	32	1	
4	4th	1.94	32	.9	
		1.06	25		
5	3rd	3	25	.8	
6	2nd	3	20	.6	
7	1st	3	20	.4	

x13+x14+x15=3;
p5-(.022*x16+.068*x17+.174*x18)>=p6;

$$p6 >= 5;$$
$$x16 + x17 + x18 = 3;$$
$$p6 - (.03*x19 + .077*x20) >= p7;$$
$$p7 >= 2;$$
$$x19 + x20 = 3;$$

The above model was solved by LINGO 14.0. The results are presented in Table 4.11. From Table 1.13 it can be seen that the optimal cost of piping system is Rs. 14627.43.

Table 13. Optimal diameter using Hazen-William's formula.

S.No.	Storey	Optimal Length (M)	Optimal Diameter (Mm)	Design Flow Rate (1/S)	Objective Values
1	7th	1.087	50	1.3	14627.43
		3.922	40		
2	6th	3	32	1.25	
3	5th	3	32	1	
4	4th	2.551	32	.9	
		.449	25		
5	3rd	3	25	.8	
6	2nd	3	20	.6	
7	1st	3	20	.4	

VI. CONCLUSION

From this study, the following conclusions can be made. A linear programming-based optimization model is developed to achieve minimum cost design of downfeed water piping system in multistoreyed buildings considering the requirements of minimum and maximum velocity through the pipes and minimum residual pressure head in each floor.

Comparison of the results from optimization model with those obtained from traditional method establishes that the developed optimization model results in more economical design of water piping system in multistoreyed buildings.Comparison of the results from optimization model for different hydraulic zones in a tall building establishes that the division of the building in suitable number of zones is also an important factor for the economic design of water piping system in tall buildings.

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