OPTIMAL DESIGN OF WATER DISTRIBUTION SYSTEM FOR KITS CAMPUS

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Abstract— Distribution network consumes a considerable part of the total expenditure incurred on water supply system and thus networking is desirable. If the network is optimized there can be significant saving in expenditure. A system of network which fulfills all the demand of the consumer with minimum installation cost is termed as optimized network. Many network design and optimization techniques are available.

The method used here for optimization is Cost Head Loss Ratio Method. This approach however is presently applicable to single-source system only. The approach is a non-computer optimization technique which is suitable for hand calculation with the help of electronic calculator.

The selected method is used for designing the water distribution system for K.I.T.S campus located at Ramtek, Nagpur District, Maharashtra and finally the total cost of the network is obtained.

Index Terms—Optimization, water demand, cost function

I. INTRODUCTION

The purpose of the distribution system is to convey wholesome water to the consumer at adequate residual pressure in sufficient quantity at convenient points. Water distribution usually accounts for nearly 60% of the capital cost of the water supply system. As such proper design and layout of the system is of great importance.

The optimal design of large looped hydraulic pipe network is achieved using genetic algorithm method is studied by Cisty et al [2]. A case study on water distribution network of Suez City, Egypt in which genetic algorithm model is adapted to optimize pipe diameters is done by Djebedjian et al [3]. A nonlinear programming approach using the successive quadratic programming is used NLP formulations can handle more general water distribution problems such as nonlinear pumping cost is studied by Varma [7]. A non-computer optimization procedure for distribution systems is evolved by Bhave [8].

By studying the literature as mentioned above it is found that the optimal design of large looped pipe network is achieved and water distribution network of different cities are carried out. And also the nonlinear programming approach are used.

II. WATER DISTRIBUTION SYSTEM

The distribution consist of pipes of various sizes, valves, meters, pumps, distribution reservoir, hydrants, stand-post, etc. The pipelines carry the water to each and every street and road. Valves control the flow of water consumed by individual as well as by town. Hydrants are provided to connect the water to the firefighting equipment during fire service. Connections are done to connect the individual building with the water line passing through the streets. Pumps are provided to pump the water mains to obtain the required pressure in the pipe line.

A. *Elevated storage reservoir*

The existing elevated storage reservoir is located near the girls hostel in this campus. It is at the height of 18 m from the ground level. The capacity of the ESR is 1.5 lack liters. The capacity of the underground storage reservoir is 1.0 Lacks liter.

B. *Methods of distribution*

Gravity system- This system is used where source is lying at the elevated place and the community is lying at the lower level than the source. This is the most reliable method. If the conduit lead in from source to the city is adequate is size and well safeguards against accidental breaks.

Pumping system- In this system water is directly pumped into the mains. Since the pumps have to work at different rates in a day, the maintenance cost increases. The number of pumps required in this system depends upon the demand of the water. High lift pumps are requires and their operations are continuously watched. If the pump fails whole supply of the town will be stopped. Therefore it is better to have dual pumps. But this system is not preferred to the other system.

Combine system- This system is also known as dual system. In this system water is pumped and stored in the elevated distribution reservoir. The excess water during low consumption remains in the elevated reservoir and it is supplied during the peak period. As in this system water comes from two sources on from reservoir and second from service station, so it is called dual system. The water stored in the elevated reservoir to meet the requirement during break down of pumps and for firefighting.

C. *Water demand*

As an essential element of information for planning is the demand function for uses with water as the input factor. As these uses are not well known as yet it is difficult to estimate them. However the functional relationship of supply and demand is cyclic. This is because water uses varies from city to city, depending upon the climate, characteristics of the environment concern, population, industrialization, and other factors. Again in some cities it varies from season to season, day to day, and hour to hour. Thus in the planning of the water supply system, the probable water use and its variations must be estimated as accurately as possible. There are various types of demand such as-

1. Domestic water demand
2. Commercial and industrial water demand
3. Fire demand
4. Demand for public uses
5. Compensate losses demand

III. COST HEAD LOSS RATIO METHOD

A. *Analysis*

In the analysis of water supply system different elements such as the location of sources and sources of water, length of raw and clean water transmission mains, locations, capacity, and different levels of reservoir, layout of distribution network are known.

Analysis of the system may be necessary to known whether the capacity of the sources is adequate, whether the available storage capacity and water levels in the reservoir at different times are satisfactory, whether the system has acceptable behavior under emergency conditions such as fire failure of pumps, pipes valves and so on.

B. *Design*

In the design of the system, however the system is unknown and the designer had to decide the location and sizes of the different components, for ex. in the design of the water supply system the designer has decide the source and source of water of acceptable quality and adequate quantity, location and sizes of transmission mains, water treatment plant and reservoir, layout of the distribution network with the size of the pipe, location and type of different valves.

C. *Parameters involved in water distribution system design*

1. Hydraulic Gradient line value:

H.G.L value of the source is known and remains constant but HGL values of demand nodes are unknown parameters.

2. Source node or supply node:

Node which supplies water to the Distribution system and the HGL values of the node remains constant also called as head node. The source node is a starting node which receives flow outside and supplies it to the network.

3. Demand node:

A distribution node or a demand node is a node which receives flow through one or more links and distributes it. From this node the water is given to the consumer.

4. Branch network:

It is a combination of several network having dead ends.

5. Node:

It is a point where two or more pipes are meeting.

6. Link:

It is a line joining two successive nodes.

7. Minimum required HGL:

It is a HGL obtained by adding residual lead Generally two meter to the reduced level.

8. Equations (Continuity Equation):

Continuity equation is based on law of conservation of mass.

$Q = Q_1 + Q_2 + Q_3$ (Balance of Flow)

If V_1, V_2 are the average velocity at section 1-1, 2-2. With c/s area A_1 & A_2 respectively, the continuity equation for volumetric flow rate in incompressible flow becomes

$Q = A_1 * V_1 + A_2 * V_2$

D. Cost head loss ratio method

Cost head loss ratio method is the method which is used for optimal design of single source network. For optimal design we are using this method in which cost factor and head loss is considered simultaneously. This method is invented by Shri. Pramod Bhave. By this method the minimum cost for the design of water distribution network is achieved. This method is more favorable as it is done manually. By this method, the optimization of network is achieved by considering the less economy in the project.

There are certain assumptions in the method which are as follows:

1. The geometrical layout of the network is known and fixed.
2. The node demand are known and fixed i.e the flow in the system is in steady state condition.
3. The diameter of the link connecting different nodes is a continuous variable.
4. The capital cost per unit length of a link varies exponentially with its diameter.

E. Optimity criteria

For a distribution network the cost function can be shown to be unimodal continuous convex function of H_i and H_j.

Consider a node j of such a network when all Hj values are assumed the direction of flow in all the links meeting at are known. Thus these links either supply to the node j or distribute from the node j. let ij, i=1…m be the supply links and jk, k=1…n be the distribution links.

$$\frac{\delta}{\delta H_j}\left(\sum_{i=1}^{M} C_{ij} + \sum_{i=1}^{N} C_{jk}\right) = 0$$

Differentiating with respect to H_j and simplifying

$$\frac{\sum_{i=1}^{m} m_{ij} C_{ij}}{H_i - H_j} = \frac{\sum_{i=1}^{N} m_{jk} C_{jk}}{H_j - H_k}$$

Or

$$\sum_{i=1}^{M} \left(\frac{mc}{H_L}\right)_{ij} = \left(\sum_{i=1}^{N} \frac{mc}{HL}\right)_{jk}$$

Thus for the entire network

$$\frac{\sum m_{ij} C_{ij}}{H_i - H_j} = \frac{\sum m_{ik} C_{ik}}{H_j - H_k} \quad ; \quad j = 1 \ldots Y$$

Or

$$\sum \left(\frac{mC}{H_L}\right)_{ij} = \left(\sum \frac{mC}{H_L}\right)_{jk} \quad ; \quad j = 1 \ldots Y$$

This gives a set of optimality criteria, termed head loss ratio criteria.

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or

$$\sum_{i=1}^{M} \left(\frac{mc}{H_L}\right)_{ij} - \left(\sum_{i=1}^{N} \frac{mc}{HL}\right)_{jk}$$

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IV. METHODOLOGY AND DESIGN

4.1 Networking

A network is selected keeping in view to cover the entire area of the proposed campus. Sixteen nodes were established for the network. The network is selected along the sides of road length.

NETWORKING:

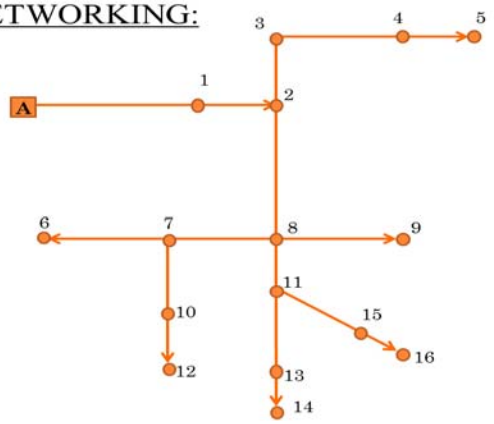

Fig: Selected water distribution network

4.2 Surveying

To know the HGL values of the nodes firstly RL of the nodes have to be known. For knowing the RL, survey of the location is required. The RL are taken with the help of Auto level. Simultaneously while taking RL, the lengths between the successive nodes are also measured and thus the total length for the various pipelines to be laid is measured.

I. Obtained reduced levels

Sr. No	Nodes To Node	Length (m)	Reduced Level
0	0	0	100
1	1	117	100.01
2	2	36	99.985
3	3	65	100.112
4	4	81	99.7
5	5	77	99.695
6	6	113	99.135
7	7	36	98.48
8	8	89	98.53
9	9	21	98.36
10	10	50	98.54
11	11	51	98.175
12	12	41	97.7
13	13	98	97.49
14	14	9	97.455
15	15	100	97.285
16	16	22	97.125

4.3 Estimation of demand

For calculation of the total demand at a source node, it is required to calculate demand at end node in the network. For the calculation of demand at the node, find out the various numbers of utilities including the population at that node. The demand and discharge at each node is to be found out and peak demand is to be calculated.

II. Different units in the campus and their demand

Node No.	Utilites involved	Total popul-ation	Per capita demand	Total demand lit/day
1	1.Worker Quarter	16	135	2160
				2160
2	1. Post Office PCO	10	15	150
	2.A Block	5	15	75
				225
3	1.B Block	100	135	13500
				13500
4	1.Jamuna Hostel	287	135	38745
	2.Jamuna Mess	287	70	20090
	3.Lawn		45	90
				58925
5	1. Triveni Hostel	351	135	47385
	2. Triveni Mess	351	70	24570
	3. Lawn		45	45
				72092
6	1.L type Quarter		135	2160
	2.R1 type Quarter	16	135	2160
	3.R2 type Quarter	24	135	3240
	4.R3 type Quarter	48	135	6840
	5.R4 type Quarter	48	135	6840
				20520
7	1.old Kaveri Hostel	128	135	17280
	2.Kaveri Hostel New	240	135	32400
	3.Kaveri Mess	368	70	31220

	4.Lawns	25	45	1125
				126245
8	1.Chairman Residence	10	135	4350
	2.Principal Residence	3	135	405
	3. New Guest House	4	135	540
	4.Old Guest House	4	135	540
				2835
9	1.Sports Complex	100	10	1000
	2.Project Engineer section	10	10	100
	3.lawns		45	45
				1145
10	1. Electrical lab	10	10	100
	2. Pump room	3	10	30
				130
11	1.Administrator Block	1400	45	63000
	2.lawn	5	45	1125
				64125
12	1.Fluid Mechanics Lab	10	100	100
	2.Lab1, Lab2	10	100	100
				200
13	1.Lawn		90	90
	2.MBA Block	270	45	12150
	3.Work Shop	20	45	900
14	1.Lawn		45	90
	2.Elec.,IT,Comp. Tech Building	590	45	26550
	3.Construction Yard			
				26640
15	1.Lawn		45	45
	2.Civil and Arch Dept.	340	45	15300
	3.Library	45	10	450
	4.Canteen	170	15	2550
	5.Fountain		$10m^3$	10000
				28345

Critical Slope is required for critical path. Calculation of the critical slope for various paths is shown in table III. The assumed HGL values s to be found out by

Assumed HGL = Ho – ScXL

III. Calculation of critical slope

Sr. No.	**Path**	**Path Length**	**Head Loss (H_L)**	**Slope = H_L /L**
1	0-1-2-3-4-5	376	6.305	0.0168
2	0-1-2-8-9	263	7.64	0.029
3	0-1-2-8-7-6	391	6.865	0.0179
4	0-1-2-8-7-10-12	369	8.3	0.0225
5	0-1-2-8-11-13-14	400	8.545	0.0214
6	0-1-2-8-11-15-16	415	8.875	0.0214

4.4 Head loss calculation

Head loss can be calculated by Hazen William Formula.

Hazen William formula: $H_L = \frac{K \times L \times QP}{C_{HW} \times D^r}$

Where,

Q = Discharge in cumec hour

D = Diameter of pipe in mm

L = length of pipe

K = Constant depends on unit of pipe and material of the pipe

C_{HW} = Hazen and Williams coefficient

Where, $C = K \times L \times D^m$

m = cost function

The values of K and m are calculated by plotting graph of log of diameter of the pipes on X-axis verses log of cost of available pipes on Y-axis on a log-log graph.

IV. Values of cost function m and constant K for cast iron

Diameter	Cost	X= log D	Y=log C
80	380	1.903	2.580
100	412	2.00	2.615
125	495	2.097	2.695
150	592	2.176	2.772
200	874	2.301	2.941

4.5 Designing

For the design of the water distribution system, the main aim is to achieve the optimization .In this paper, the cost head loss ratio method is used. This method is evaluated by using the successive iteration with respect to cost of the network. The iteration gives the correction of the HGL values. The diameter of pipes obtained is converted to commercially available diameter.

V. HGL values of different node

Sr No	Node No	Length	Reduced Level	Min HGL	Max HGL
0	0	0	100	118	-
1	1	117	100.01	112.01	116.04
2	2	36	99.985	111.98	115.3
3	3	65	100.112	112.11	114.33
4	4	81	99.7	111.7	112.97
5	5	77	99.695	111.69	111.69
6	6	113	99.135	111.13	111.13
7	7	36	98.48	110.48	113.33
8	8	89	98.53	110.53	113.93
9	9	21	98.36	110.36	110.36
10	10	50	98.54	110.54	112.49
11	11	51	98.175	110.17	113.07
12	12	41	97.7	109.7	109.7
13	13	98	97.49	109.49	111.43
14	14	9	97.455	109.45	109.45
15	15	100	97.285	109.28	111.39
16	16	22	97.012	109.12	109.12

VI LENGTH OF THE LINK AND DISCHARGES

Sr. No.	Nodes To Node	Length (m)	Q (m^3/min)
1	0-1	117	0.5988
2	1-2	36	0.5965
3	2-3	65	0.1921
4	3-4	81	0.1779
5	4-5	77	0.1159
6	7-6	113	0.0214
7	9-7	36	0.2584
8	2-8	89	0.4041
9	8-9	21	0.0012
10	7-10	50	0.1054
11	8-11	51	0.1401
12	10-12	41	0.0001
13	11-13	98	0.016
14	13-14	9	0.0128
15	11-15	100	0.0573
16	15-16	22	0.0295

In this paper, cost head loss method is used. This method is evaluated by using the successive iteration with respect to cost of the network. The iteration gives the correction of the HGL values.

VII. Correction in HGL of intermediate nodes in 4^{th} iteration

Demand Node	Min. HGL	Assumed HGL	Correction in HGL
1	112.01	115.94	0.18
2	111.985	115.28	-0.281
3	112.112	114.108	0.105
4	111.7	112.77	-0.043
7	110.48	111.57	-0.115
8	110.53	112.76	-0.132
10	110.454	110.74	-0.986
11	110.175	112.16	-0.368

13	109.49	109.66	0.011
15	109.28	109.62	-0.084

VIII. Length of pipe and cost of pipe required for networking

Diameter	Length (m)	Rate per meter	Total cost
125	136.8	495	67740.75
100	129.2	412	53209.8
80	92.4	380	35112
75	177.8	218	38760.4
60	101.4	193	19750.2
50	33.8	112	3785.6
40	16	98	1568
25	104.4	68	7099.2
20	8.6	56	481.6
12	162	40	6480
Total Cost			233807.55 Rs.

V CONCLUSION

In this paper, the economy is achieved. This is achieved by adopting the cost head loss ratio method. The calculated diameters for various links are not commercially available in the market. so, the calculated diameters are converted into commercially available diameters. The correction obtained from each iteration gives the value of the assumed HGL if the assumed HGL values are less than the minimum required HGL values.

An attempt was made by cost head loss ratio method to optimise the Water distribution network for KITS campus. The cost of the network is reduced in each successive iteration. The total cost estimated for the distribution network is the summation of the cost of each pipe.

THE TOTAL COST OF PIPE LINE= 2,33,807.50Rs.

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