International Journal of Engineering Research
Volume No.5, Issue Special 1 pp : 172-174

ISSN:2319-6890(online),2347-5013(print)
8 & 9 Jan 2016

Optimal Design of Water Transmission System with Pumping

R. K. Rai, R. S. Tetu
Department of Civil Engineering, Government College of Engineering, Amravati, 444606 Maharashtra, India
E-mail: rairampravesh@yahoo.co.in, rashmitetu11@gmail.com

Abstract: ***Applying mathematical models to obtain optimal solution for water transmission system has been of major concern during the last few decades. Optimization problem for water transmission system is considered as a non-linear problem during the search process to identify the decision variables (i.e. pipe diameter and cost of pipe and pump). In this paper, flow path algorithm has been adopted to obtain the optimal design of the basic unit of water transmission system involving pumping i.e. three reservoir systems. The effect of pumping head on the optimal design of water transmission system has been considered in this work.***
Keywords: Flow path algorithm, Lagrange multiplier method, Optimization, Water transmission system

I. Introduction

Water from various sources of water such as river is taken to the water treatment plant to purify and treat the raw water so as to make the same suitable for drinking purpose. The treated water from water treatment plant is transported first to the clear water sump. From clear water sump, the water is transported to master balancing reservoir (MBR). Then, the water is transported from MBR to the elevated service reservoir (ESR). The pipeline from clear water sump to MBR is known as trunk transmission line, and the line of water from MBR to elevated service reservoir (ESR) is known as zonal transmission line. The trunk transmission lines and the zonal transmission lines are commonly known as water transmission lines. This paper deals with the design of the basic unit of water transmission systems. The design of water transmission line requires large diameter pipe along with its accessories such as air relief valves, scour valve, sluice valve *etc.*, and these pipes as well as accessories involves huge cost. Therefore, there is a need to obtain the optimal design of such water transmission systems thereby a substantial reduction in the overall cost of the water transmission lines can be achieved. An algorithm for the optimal design of a water transmission system has been developed in such a way that it determines the optimal diameter, and the optimal cost of water transmission pipelines. In this paper, procedure for the optimal design of water transmission lines for three reservoir systems using Hazen-Williams equation has been developed.

II. Review of Literature

The main objective of the literature review is to explore the related studies on the optimization of water transmission system. Shamir (1974) developed a methodology for the optimal design and operation of a water distribution system that operates under one or several loading conditions. It was concluded that the method was computationally feasible.

Bhave (1985) developed a method for the optimal expansion of water distribution systems subjected to a single loading pattern. The method was iterative and converges rapidly to a local but fairly good optimal solution. Examples of the method were presented, including its application to the expansion of the New York City water supply tunnel system.

Sarbu (2010) studied the optimization of water distribution networks supplied from one or more node sources, according to demand variation. Traditionally, in pipe optimization, the objective function was always focused on the cost criteria of network components. Sarbu (2010) developed an improved linear model which has the advantage of using not only the cost criteria, but also the energy consumption, consumption of scarce resources, operating expenses *etc.* Sarbu (2010) compared the linear optimization model with the other models. The model was based on the method of linear programming and allows the determination of an optimal distribution of commercial diameters for each pipe in the network and the length of the pipes which correspond to these diameters.

III. Hydraulic Equation

The Hazen-Williams equation originally introduced in 1902 is empirical and dimensionally non homogeneous equation. It is the most widely used equation for the design of pressure mains. The Hazen-Williams equation is applicable for smooth turbulent flow. The Hazen-Williams equation relating velocity of flow, hydraulic mean radius and hydraulic gradient is given by:

(1)

Where, C_H = Hazen-Williams constant; R = Hydraulic mean depth, m; and S = Slope of pipe.

The continuity equation is given by:

(2)

Where, Q = Flow of water, m^3/s; and A = Cross sectional area of flow, m^2.

Combining Equations (1) and (2), Equation (1) can be written in terms of Q as:

(3)

Equation (3) can be rewritten as:

(4)

The head loss in a pipe can be calculated using Equation (3) for known values of C_H, Q and D. The value of C_H for CI pipe is 100 (Manual, 1993). The required diameter of a pipe can be obtained from Equation (4) for known values of h_f , C_H and Q. Thus, design of a pipe using Hazen-William equation is very simple because the value of C_H is constant for all types of flows.

IV Cost Functions

Cost of Pipe

Optimal design of a water transmission pipeline requires cost of its components. In order to construct an objective function based on the total cost of water transmission system, the cost structure for the components of the water transmission system has to be investigated. The pipes and accessories are the major components which share a substantial portion of the overall cost of water transmission system. Generally, cast iron (CI) pipes are used for water transmission system because these pipes are resistant to corrosion and are durable. The cost of pipe is given by (Swamee, 1993):

(5)

Where, k_m and m = Cost parameters of pipe; L_i = Length of the i^{th} pipe, *m*; and D_i = Diameter of the i^{th} pipe, *m*.
In order to determine the cost of pipe, the cost of pipe per meter length for CI pipe was taken from the schedule of rates, Maharashtra Jeevan Pradhikaran for Nagpur and Amravati region. Variation in the cost of pipes versus diameter of pipe is shown in Fig. 1. The values of cost parameter for CI pipes were found to be k_m = 41072 Rs. and m = 1.405 with R^2 = 0.994.

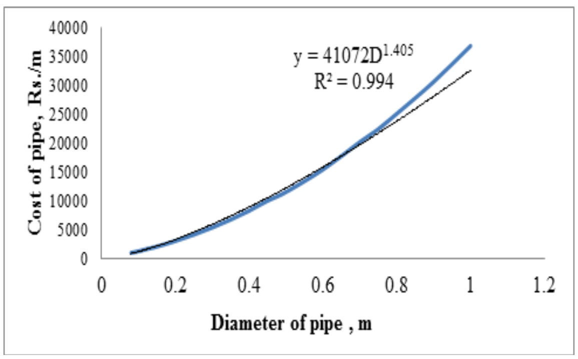


Fig. 1: Diameter versus cost of pipe

Cost of Pump

The water supply source may be a river or a lake intake or a wall field. The other pertinent works are the pumping plant and the pump house. The cost of pump house is not of much significance to be worked out as a separate function. The cost pumping plant C_p along with all accessories and erection charges, is proportional to its power *P*.

(6)

Where, *P* = Power of pump is expressed in kW; and k_p and m_p = cost parameter for pumps and motors. The power required is given by:

(7)

Where, ρ = mass density of fluid; η = combined efficiency of pump and primer mover. Cost of pump can be calculated by:

(8)

For a known set of pumping capacities and cost data, the and can be obtained by plotting a graph. The pump and pumping station cost data was plotted in graph 1 and can be represented by the equation:

(9)

Thus, and As the cost of the pumping plant is considerably less than the cost of energy, by suitably adjusting the coefficient , the exponent m_p can be made as unity. This makes the cost to linearly vary with *P*.

Cost of Energy

The annual recurring cost of energy consumed in maintaining the flow depends on the discharge pumped and pumping head h_0 produced by the pump. If *Q* = the peak discharge, the effective discharge will be F_A, F_D, *Q*. The average power *P*, developed over a year is given by:

(10)

Where, F_A =Annual averaging factor; and F_D = Daily averaging factor for the discharge.
Multiplying the power by the number of hours in a year, 8760 hours and the rate of electricity R_e in Rs./kWH, the capital cost of energy C_e consumed in maintaining the flow is given by:

(11)

V. Description of Water Transmission Line

Three reservoir one junction system is the basic unit of the multi-reservoir multi junction pipes, three reservoirs and one junction as shown in Figure 2. For the purpose of optimal design of water transmission system, the pipes, reservoirs and reservoir elevations have been assigned numbers using the following rules:

1. The last or the lowest reservoir is assigned number 1 and the highest reservoir is assigned the number 2;
2. The junction on the mainline are assigned number j_1;
3. The intermediate reservoir is assigned numbers.

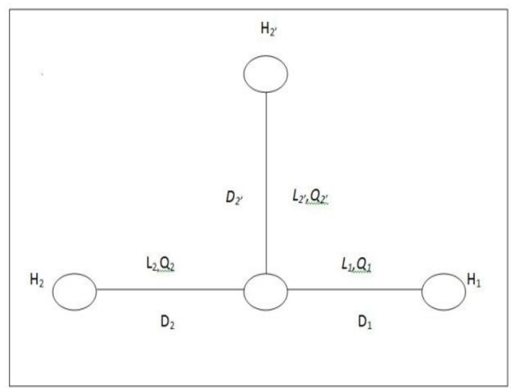


Fig. 2: Three reservoir system

Table 1: Design data for three reservoir system

Pipe / Reservoir	*H* (m)	*L* (m)	*Q* (m^3/s)
2	51.5	8000	0.8
2'	51.0	2000	0.3
1	50.0	5000	0.5

VI. Illustrative Design Example

The process of optimal design of three reservoir water transmission system is illustrated using an illustrative design example I. The design data for the design example I containing the elevation of the reservoirs, length of pipes and flow in each pipe are given in Table 1.

VII. Result and Discussions

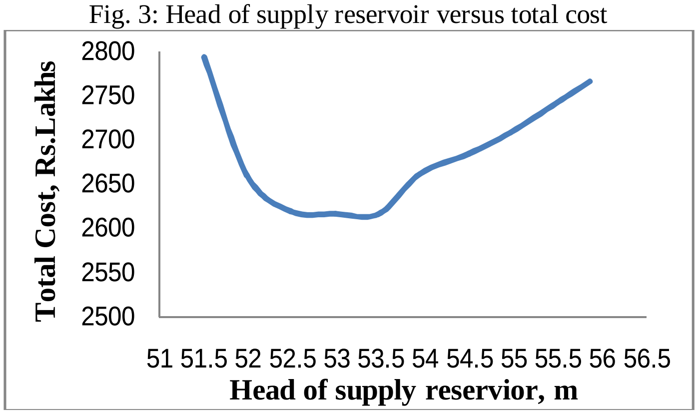
ISSN:2319-6890(online),2347-5013(print)
8 & 9 Jan 2016

The cost of pumping, cost of pipe and the total cost is given in following Table 2.

Table 2: Set of Pumping Head versus Total Cost

Sr. No.	H	Cost of Pipeline	Cost of pumping	Total cost (Rs.Lakhs)
			(Rs. Lakhs)	
1	51.50	1265.2	1529.08	2794.31
2	51.99	1078.0	1582.6	2660.60
3	52.48	984.2	1636.12	2620.40
4	52.98	926.5	1690.72	2617.23
5	53.47	872.4	1744.25	2616.75
6	53.94	851.4	1795.57	2662.17
7	54.49	814.3	1855.65	2684.98
8	54.98	786.9	1906.98	2708.84
9	55.49	763.4	1964.87	2743.005
10	55.86	747.2	2005.28	2767.29

Fig. 3: Head of supply reservoir versus total cost



VIII. Conclusions

In water supply transmission systems, optimization techniques applied to minimize the cost of water distribution networks. Optimization model is developed to select the optimal design of water transmission system using pumping. The model minimizes total annual cost of pumping main and pump, including escalation in the capital and energy costs. The developed model will be helpful to select optimal head with discharge range and corresponding efficiency range for a particular pump. The model can also be used to evalute existing pumping systems to predict optimum time to repair or replace the pump.

References

i. Bhave, P. R. (1985) “Optimal expansion of water distribution systems”, *Journal of Environmental Engineering, ASCE, Vol.11, No. 2, pp.177-197.*

ii. MJP, (2012-2013) “Schedule of Rates for Maharashtra Jeevan Pradhikaran Works for the year 2012-2013”, *Maharashtra Jeevan Pradhikaran, Nagpur-Amravati Region, Nagpur.*

iii. Sarbu, I.(2010) “Optimization of water distribution networks”, *Proceedings of the Romanian Academy, Series A,Vol. 11, No. 4, pp. 330–339.*

iv. Shamir, U. (1974)“Optimal design and operation of water distribution system”, *Water Resources Research, ASCE, Vol. 10, No. 1, pp. 27-36.*

v. Swamee, P. K., and Sharma, A. K. (2008)“Design of Water Supply Pipe Networks”, *John Willey and Sons, INC., Publication, Hoboken, New Jersey, Canada.*

vi. Swamee, P. K. (1996)“Design of multistage pumping main”, *Journal of Transportation Engineering, ASCE, Vol. 122, No. 1, pp. 1-4.*

vii. Swamee, P. K. (2001)“Optimal design of pumping mains”, *Journal of Transportation Engineering, ASCE, Vol. 127, No. 3, pp.264-26*