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EFFECT OF GENETIC ALGORITHM PARAMETERS ON COST OPTIMIZATION OF PIPE NETWORK: A CASE STUDY

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Abstract - This paper deals with the cost optimization of a pipe network using the technique of Genetic Algorithm. The software used for this purpose is WaterGEMS. Genetic Algorithm uses various factors for optimizing the cost and these factors depend upon the size of the network. An appropriate value of each factor is fixed by conducting sufficient number of trials and then a solution is obtained which gives the minimum cost.The method is first validated by a bench mark problem of two loop network given in literature. In the present study G.A. is applied for the cost optimization of a village pipe network of Budni block of Sehore district in M.P. (India) by changing the reservoir height. It is seen that the least cost of this pipe is attained at reservoir height of 19.4m.

Keywords: Pipe Network optimization, Genetic Algorithm, Reservoir height.

I. INTRODUCTION

A water distribution network may be defined as a system which consists of pipes, reservoirs, pumps, valves, connected to each other to provide sufficient water to consumers. Huge amount of capital is being spent in designing new water distribution system and for rehabilitation of existing network. Now days, water supply system has become very important parameterfor the prosperity of any countrythe most important component of water supply system is Water Distribution Network (WDN) which accounts for nearly 70% of the total cost. The designer aims at fulfilling the demand at every junction in the network.

Various aspects such as, material availability, infrastructure, hydraulics, reliability, water quality, and demand patterns are to be considered for optimal design of water distribution network. The problem of Network optimization basically deals with determination of pipe sizes which ensure a feasible least cost solution from a set of commercially available diameters.

Several Researchers have applied various techniques in the past to optimize water distribution network. Alperovits et al (1977) proposed a linear programming gradient method (LPG) for optimization of a looped water distribution system.

Gupta et al (1999) developed a methodology based on genetic algorithm for lowering the design cost of new water distribution networks and augmentation of existing ones. Afshar et al (2009) studied the application of a compact Genetic Algorithm to pipe network optimization problems. Compact genetic algorithm was proposed to reduce the storage and computational requirements of population-based genetic algorithms.

Chandramouli et al (2011) developed a new parameter for assessing the overall network reliability using fuzzy logic concepts based on the excess pressure available at demand nodes. The objective was to incorporate the parameter in a two objective optimization model for design of water distribution network using the combination of EPANET and Genetic Algorithms tool kit in the MATLAB environment.

Ramesh et al (2012) generated satellite based thematic layers and GISbased census data to estimate water demand and design of water transmission lines. Cost-effective expenditure on the design of pipe network is essential to achieve a sufficient quality service due to an ever-tightening budget.

Most of the methods of cost optimization in case of water distributionnetworkoptimize the pipe diameters to get minimum pressure head at required demand, so as to get a minimum cost at fixed reservoir height. In the present work an attempt is made to minimize the pipe cost of WDN by changing the reservoir height.

A WDN of village network of Budni block of Sehore district is optimized in the present work. The network is designed to supply water to a bunch of six small villages whose total projected population after 20 years (i.e. for the year 2035) is 5035. One water tank is used to supply water for 6 hours in a day. The network is designed by using limited no. of pipe sizes to fulfill the demand of 80 lpcd at minimum pressure head of 7 meters at each node. The effect of various GA parameters and tank height on the pipe cost is presented graphically and in tabular form.

A. Genetic Algorithm

Genetic Algorithm (GA) is an optimization method that can be used for solving many complex problems which are quite difficult to solve using the traditional methods of linear and non-linear programming. (Goldberg, 1989; Michalewicz, 1994; Savic and Walters, 1997; Hrstka and Kucerova, 2004).

GA provides an efficient way to obtain optimal solutions by following principal of natural genetics. In nature, the fittest speciessurvive to propagate and produce offspring, whereas the weak ones are eliminated through competition. Analogously, in GA, the solution which fits best in the existing circumstance is retained and used for further calculation. The most feasible variables and solution are consequently generated.The possible solution is defined as a chromosome which is subdivided into genes. The problem constraints are fixed at the beginning and GA starts with an initial population of randomly generated chromosomes. The new populations are then generated and evaluated through iterative, random and probabilistic mechanisms which are ruled by the fundamental operators of parent selection, crossover, replacement and mutation (Marseguerra and Zio, 2000; Montesinos et al., 2001).By this approach, a positive fitness function is generated from the objective function that measures the chromosome suitability as well as its performance to satisfy theobjective of the problem. Basically, fitness function is the criteria for evaluating the fitness of each chromosome and the one which fits best will be selected to the next generation. In optimization programming, the fitness function is assigned according to the objective function.

The solutions of complex and conflicting problems requiring simultaneous solutions, or deadlocked problems, can now be obtained with GA. Furthermore, the GA is a mathematically guided algorithm as the optimal solution obtained is evolved from generation to generation without stringent mathematical formulation.

II. PROBLEM FORMULATION

Objective function: It is to minimize the cost of water distribution network by selecting commercially available pipe diameter and the objective function is given as;

$$Min\ Cost = \sum_{i=1}^{m} C(L, D)$$

Where Cost = total cost, m = no of pipe in the network, C= cost of the pipe having length L and diameter D. The constraints to be satisfied for minimizing the cost of network are;

Constraint 1: Diameter Constraint
Diameters of the pipe are to be selected from available set of commercialy available pipe diameters. Commercially available pipe size and cost of unit length is given in tabular form.

Constraint 2: Head Constraint
The head available at each junction must be greater than the minimum required head to supply sufficient amount of water at the junction.i.e.

$$H_r \geq H_{min}$$

Where r = 1, 2, 3………………..n

Apart from these two constraints, the network is analyzed to meet the following requirement.

1. The continuity equation i.e. the amount of water entering to the junction must be equal to the amount of water leaving from the junction.

$$\sum_{j=1}^{j=n} Q = 0 \quad \text{……… (I)}$$

Where n = no of pipe meeting at any junction

2. Net head loss within the loop must be zero.

$$\sum_{p=1}^{p=nop} H_{Loop} = 0 \quad \text{……….. (II)}$$

Where nop = number of pipes

III. VALIDATION

For the purpose of validation a benchmark network with known optimal solutionis selected. Itis used to validate the methodology.

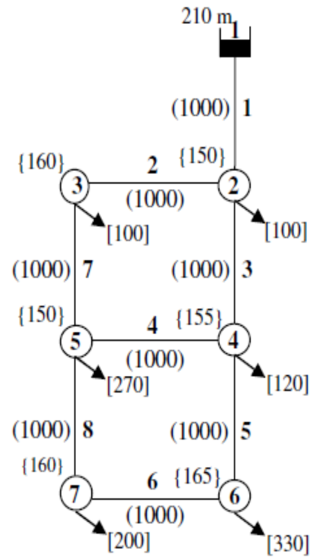

Fig. 1. Water distribution network used for validation (Babu and Vijayalakshmi, 2013)

The two loop network used for validation purpose is shown fig.1. The network consists of one source node, six demand nodes, and eight pipes. The demand and elevation at each junction and pipe length for each pipe is also shown. The hydraulic-head available at the source (node-1) is 210 m. The minimum hydraulic-head to be maintained at each junction is 30 m. The value of Hazen William's roughness coefficient which represents the pipe material, age, and surface irregularities is adopted as 130 because this value has been used by earlier researchers. Commercially available diameters along with their cost are mentioned in the table 1. For optimal design, GA parameters are as follows: mutation probability = 1.9, maximum trials = 30000, population size = 10. Results obtained are compared with the available results of (Babu & Vijayalaxmi 2013).

The cost obtained after optimization is 4,18,997.97 units which is very near to the total pipe cost available in results of Babu et al (2013) i.e. 4,19,000.00 units.

Pipe diameter and hydraulic head are compared in table 2.

Diameter	Cost (units)
25.4	2
50.8	5
76.2	8
101.6	11
152.4	16
203.2	23
254.0	32
304.8	50
355.6	60
406.4	90
457.2	130
508.0	170
558.8	300
609.6	550

Table 1. Commercial pipe dia. and cost used for two loop network

Pipe	Diameter (Babu & Vijayalakshmi)	Diameter (Obtained from present analysis)	Node Number	Pressure Head (Babu & Vijayalakshmi)	Pressure Head (Obtained from present analysis)
1	457.2	457.2	1	210 (given tank ht.)	210
2	254.0	254.0	2	53.25	53.11
3	406.4	406.4	3	30.46	30.37
4	101.6	101.6	4	43.25	43.32
5	406.4	406.4	5	33.81	33.74
6	254.0	254.0	6	30.44	30.37
7	254.0	254.0	7	30.55	30.48
8	25.4	25.4			

Table 2. Result Comparison with research work of Babu and Vijayalakshmi (2013)

IV. STUDY AREA

The study area is located in Sehore District of Madhya Pradesh within the geographical grids of latitude 22°53’20.17’’N to 22°55’3.69’’N and longitude 77°50’23.03’’E to 77°52’54.04’’E. The network of the study area is shown in fig. 2 which consists of 231 pipes of various diameters (mentioned in table 3) and 209 junctions. Minimum pressure head to be maintained at each junction is 7 m.

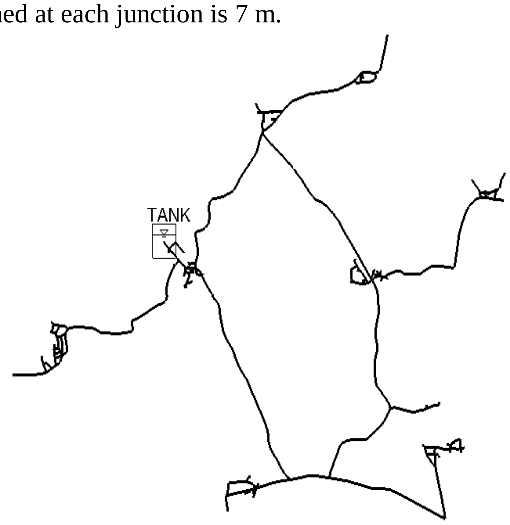

Fig. 2 Village WDN used for the analysis

V. METHODOLOGY

The data used for this case study include; topographical map of the concerned area, water distribution parameters such as; water demand, population of area, distribution network parameters such as; elevations, available pipe diameters, pipe length. WaterGEMS software is used for analysis and optimization.

The proposed network is designed for 20 years so the population after 20 years (i.e., 2035) is predictedby using the population of last 30 decades. High Density Poly Ethylene (HDPE) Pipes are used in this network. The internal diameters of the pipe and their cost are given in table 3.

The water demand is considered as 80 lpcd. The water is to be supplied for 6 hours per day. At first, the tank height was varied and a feasible tank height satisfying required pressure heads and giving minimum cost was selected. Thereafter, various GA parameters such as Penalty Factor, Cut Probability, and Maximum Trials were varied and a particular solution giving minimum cost was obtained.

Table3. Available Pipe Dia. & Cost for village WDN

Available Dia.(mm)	Cost per meter (units)
81.3	392.43
99.4	581.63
112.9	754.12
126.5	945.85
144.6	1232.79
162.7	1557.76

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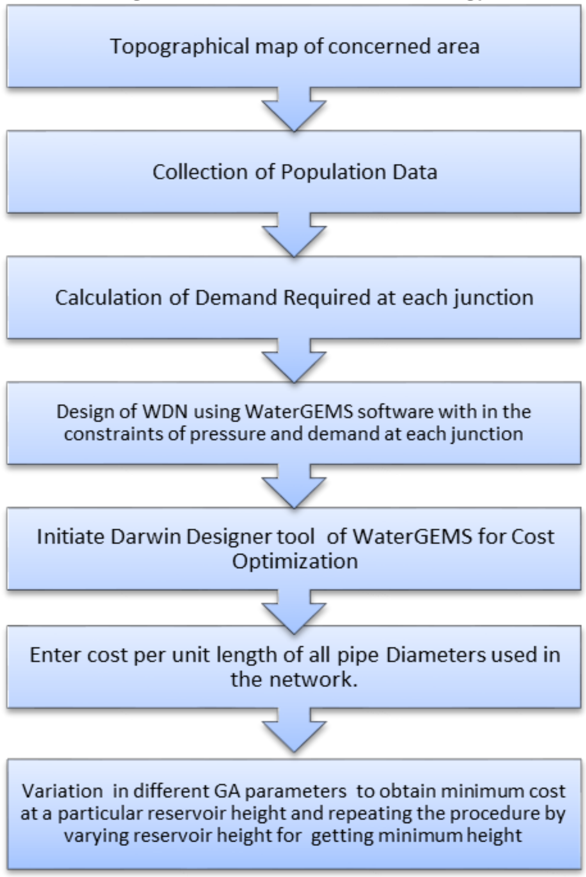
Fig. 3 Flow Chart of methodology



RESULTS

The obtained results are shown below in the form of graphs. The optimal cost came out to be 12,032,126 units at a tank height of 19.4 m. As seen from the graphs, the values of parameters for optimal solution are Penalty Factor = 200000, Cut Probability = 1.4, Max. Trials = 500000.This is because at the height of 19.4 m the combination of pipe used in the network is satisfying the objective function and constraints at least cost of pipes.

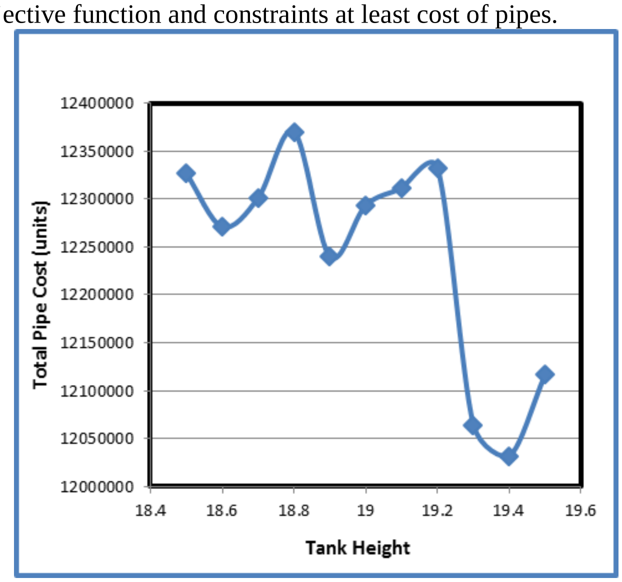


Fig. 4 Variation of pipe cost with tank height

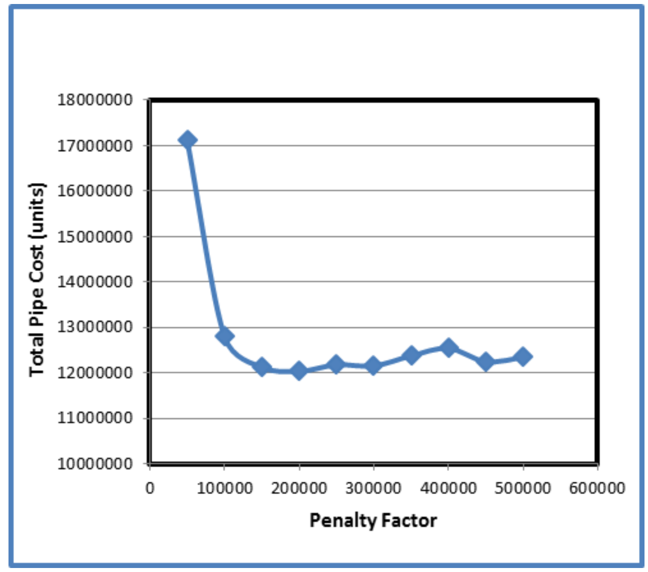


Fig. 5 Variation of pipe cost with penalty factor

As seen from the graph in fig. 5 the variation of total Cost with penalty factor is not linear Initially, with increase in penalty factor the cost decreases and attains a minimum value at a penalty factor of 200000 and then increases slightly with penalty factor.

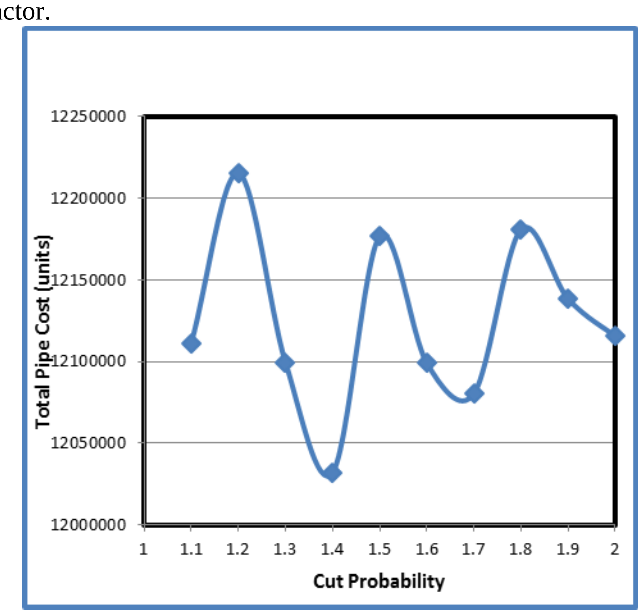


Fig. 6 Variation of pipe cost with Cut Probability

The variation of total pipe cost with cut probability is shown in fig.6. This shows that pipe cost does not follow a regular pattern with cut probability. It varies randomly and minimum cost is obtained at cut probability of 1.4.

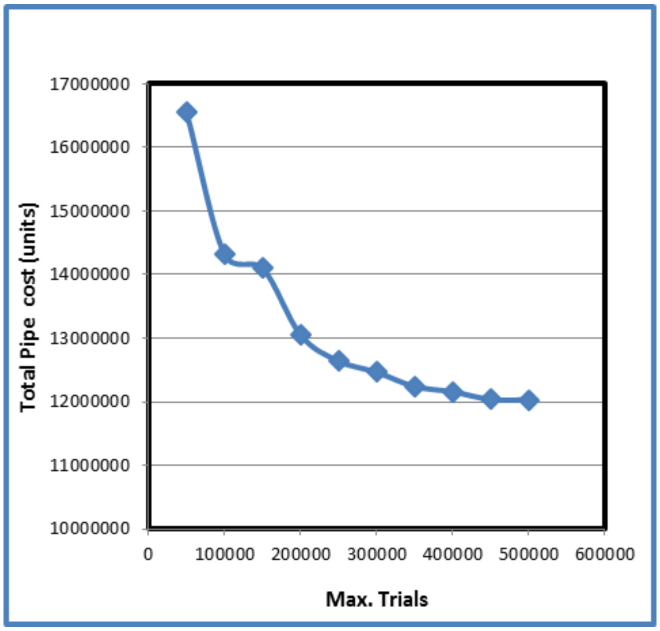


Fig. 7 Variation of pipe cost with max. Trials

It is seen in fig.7 that the total pipe cost is decreasing with no of trials and attains a constant value after 50000 trials.

VI. CONCLUSION

The present pipe network optimization concludes that G.A. PARAMETERS plays an important role in water distribution network optimization. The tank height affects the pressure and velocity distribution in the network which decides the pipe sizes and thus cost of pipe network. In this study the minimum cost 12,032,126 units of the present village network is achieved at thetank height of 19.4 m.

VII. ACKNOWLEDGMENT

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