# CHAPTER 6: VALIDATION OF GA SIMULATION RESULT ON EXISTING PIPE NETWORK

## 6.1 Introduction

Water for all is the government's objective made and to make it available at minimum cost. The determination of the optimal selection of system mechanisms requires techniques that can be engaged to assist the decision-maker in finding the appropriate solution within the feasible range. GA have been applied as search techniques for several engineering problems such as structural design optimisation, water distribution network optimisation.

Water distribution system (WDS) design problem is formulated and solved here as a single-objective optimisation problem with the choice of pipe diameters as the decision variables. The optimisation problem is resolved using a single-objective genetic algorithm (GA). The objective of the optimum design model presented here is to minimize total design costs under the constraint of minimum head requirements in steady state condition and minimum discharge requirement at different nodes.

The main variables of optimisation of Water distribution system (WDS) design problem is pipe diameter since this parameters determine major cost of the system. Neglecting the other cost involved in pipe network, experiments were carried out on the pipe to set up with several combinations of pipes in order to obtain pressure head and discharge at pipe junction results to validate GA simulation results. Aim of this chapter is to optimize the existing pipe network at the college campus by using Genetic Algorithm.

## 6.2 Field Network Problem

The pipe network of Ambition Institute of Technology (AIT), Varanasi, campus is used for our practical verification of optimisation technique. Network shows solid lines representing the existing system, Red lines depicting the new pipes (future expansion plan) and elevations and pipe lengths are shown in figure-6.1.

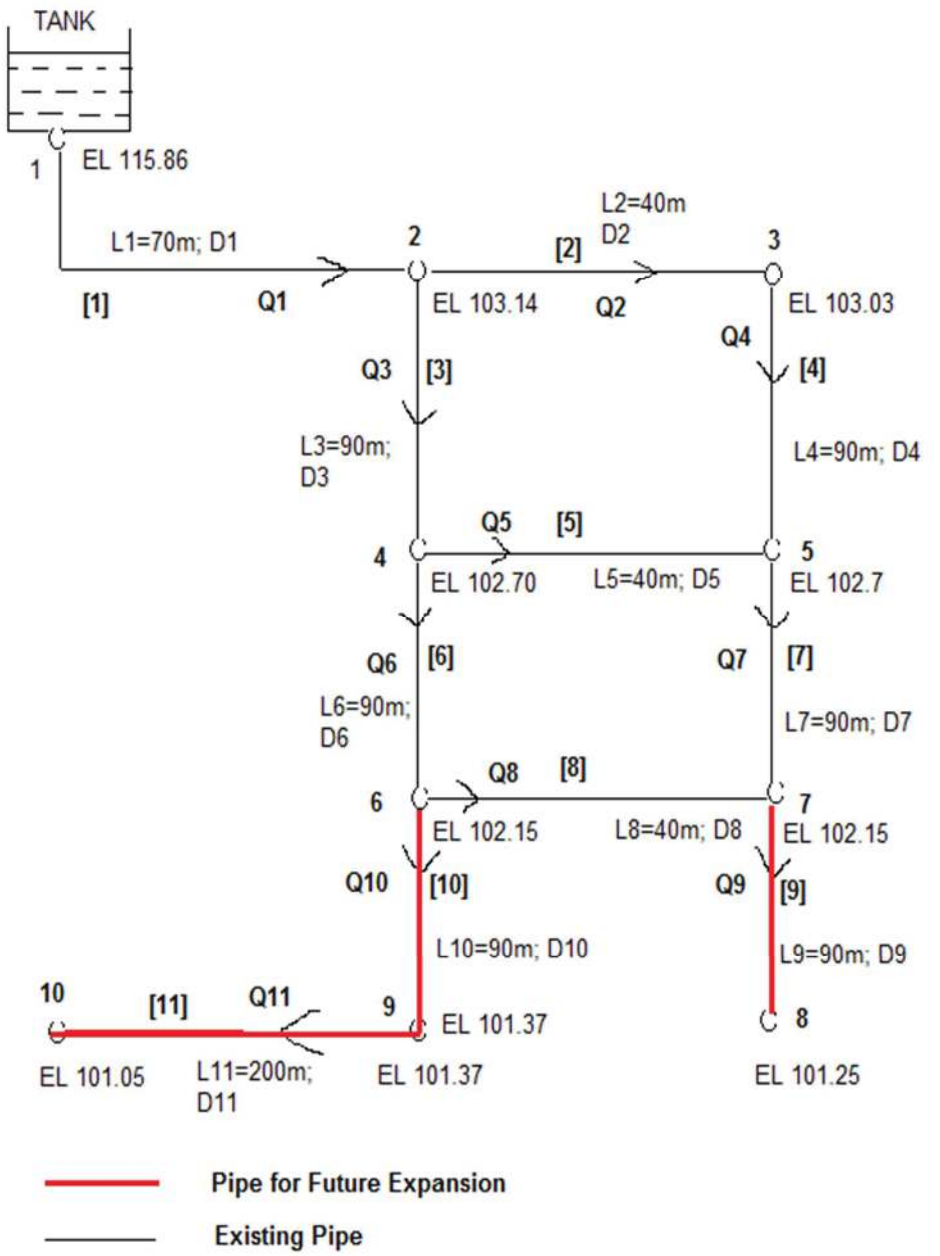


**Figure- 6.1 Pipe Network for Water Distribution at Ambition Institute of Technology (AIT), Varanasi**

The network has following features.

**a.** Hazen-Williams coefficients (C) =100 for all pipes are considered.

**b.** Friction factor for all pipes f=0.02 are taken.

**c.** Selection of three new pipes [pipe number (9), (10) and (11)] from Commercially available pipe.

**d.** Pressure head and Demand pattern at all nodes are given in table-6.1

**e.** Available Pipe Sizes and Associated Costs

1. Commercially available pipes Price List is given below in table-6.2 (JINDAL PIPES LIMITED, INDIA, wef 08/01/2015).
2. M.S. G.I. Pipes (Heavy) As per IS:1239(1) is being used here.

**Table-6.1 Pressure Head and Demand Pattern at Different Node**

| Sl No. | Node | Demand | | Minimum Pressure Head | |
|---|---|---|---|---|---|
| | | Liter/hour | $m^3/s$ | Kg / $m^3$ | in meter |
| 1 | 2 | 2000 | $5.5 \times 10^{-4}$ | 1.2 | 12 |
| 2 | 3 | 2000 | $5.5 \times 10^{-4}$ | 1.2 | 12 |
| 3 | 4 | 2000 | $5.5 \times 10^{-4}$ | 1.1 | 11 |
| 4 | 5 | 2000 | $5.5 \times 10^{-4}$ | 1.1 | 11 |
| 5 | 6 | 2000 | $5.5 \times 10^{-4}$ | 1.0 | 10 |
| 6 | 7 | 2000 | $5.5 \times 10^{-4}$ | 1.0 | 10 |
| 7 | 8 | 2000 | $5.5 \times 10^{-4}$ | 1.0 | 10 |
| 8 | 9 | 2000 | $5.5 \times 10^{-4}$ | 1.0 | 10 |
| 9 | 10 | 2000 | $5.5 \times 10^{-4}$ | 1.0 | 10 |

**Table-6.2 Price List for Jindal Pipes Limited, India, w.e.f. January, 08, 2015)**

REGISTERED OFFICE
1/5006 1st Floor Jaisav Place,
Bazaar Sirkiwalan Hauz Qazi,
Delhi - 110006
T +91 11 23210900 23214711
F +91 11 23215677

Authorised Distributors of :

**PRICE LIST OF JINDAL PIPES LIMITED WEF : 08/01/2015**

**M. S. Black Pipes As per IS: 1239 (1)**

| Size | | Light | Medium | Heavy |
|---|---|---|---|---|
| Inches | MM | | | |
| 1/2" | 15 mm | 49.50 | 58.20 | 69.60 |
| 3/4" | 20 mm | 72.50 | 75.90 | 91.80 |
| 1" | 25 mm | 100.00 | 117.35 | 138.00 |
| 11/4" | 32 mm | 128.30 | 146.80 | 177.70 |
| 11/2" | 40 mm | 160.85 | 171.90 | 206.70 |
| 2" | 50 mm | 204.80 | 241.30 | 295.80 |
| 21/2" | 65 mm | 290.90 | 306.80 | 387.60 |
| 3" | 80 mm | 337.60 | 392.60 | 464.60 |
| 4" | 100 mm | 482.40 | 575.60 | 684.50 |
| 5" | 125 mm | **** | 744.90 | 844.20 |
| 6" | 150 mm | **** | 888.60 | 1003.00 |

**M. S. G. I. Pipes As per IS: 1239 (1)**

| Size | | Light | Medium | Heavy |
|---|---|---|---|---|
| Inches | MM | | | |
| 1/2" | 15 mm | 72.90 | 87.10 | 99.9 |
| 3/4" | 20 mm | 100.80 | 109.90 | 120.40 |
| 1" | 25 mm | 137.70 | 160.70 | 176.00 |
| 11/4" | 32 mm | 175.70 | 206.40 | 226.00 |
| 11/2" | 40 mm | 221.8 | 240.00 | 262.85 |
| 2" | 50 mm | 275.90 | 319.60 | 350.00 |
| 21/2" | 65 mm | 372.30 | 403.40 | 441.75 |
| 3" | 80 mm | 439.00 | 522.20 | 571.80 |
| 4" | 100 mm | 613.20 | 756.50 | 828.45 |
| 5" | 125 mm | **** | 999.90 | 1084.10 |
| 6" | 150 mm | **** | 1191.00 | 1292.30 |

| Terms & Conditions |
|---|
| 1. Rates are Inclusive of Excise Duty |
| 2. Rates are Ex Godown |
| 3. Sales Tax is Extra as applicable |
| 4. Incase of increase in steel prices revised prices will be charged against Pending Order |

No.69

BRANCH OFFICE :
A 56/7 DLF Phase I,
Near Megamall,
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alliedtubes@hotmail.com
www.alliedtubes.in

## 6.3 Field Validation

The schematic layout of the water distribution pipe network of AIT campus used in the study is shown in Fig. 6.1. The network consists of M.S. G.I. Pipes (Medium) As per IS: 1239(1) of different diameter. The elevation of different pipe junction (node) and the length of the pipe is taken from the drawing available at site. The physical verification is also done by measuring the length of the existing pipes. To measure the pressure and discharge at nodes, the measurement devices are used as shown in the figure (6.2) and figure (6.3). The water distribution network diagram shows the pipe line in red colour, indicating the future expansion of the institute. It is numbered as pipe number [9], [10] and [11]. The diameter of pipe is adopted from the drawing at site.

### 6.3.1 Instrumentation

Different type of instrument is used for the measurement of pressure and discharge at different nodes of the pipe network system.

#### 6.3.1.1 Pressure Measurement Device

Pressure head at nodes are measured with the help of pressure gauge as shown in figure-6.2.

**Figure- 6.2 Pressure Gauge for Measuring of Pressure**

### 6.3.1.2 Discharge Measurement Device

Discharge at nodes are measured with the help of Rotameter as shown in figure-6.3. The device can measure discharge up to five thousand litre per hour.

**Figure- 6.3 Rotameter for Measuring of Discharge**

## 6.3.2 Experimental Procedure

The pressure and discharge are measured at each nodes with the help of pressure gauge and Rotameter. For this purpose, the pipe joints are opened and the instruments are attached which directly display the reading as shown in diagram. Precaution has been taken with handling the Rotameter, the instrument must be vertically attached to the pipe.

During every flow rate measurement proper time should be given to stabilize the indicated value in instruments. All the data is collected as shown in table-6.1. The other details are accepted from the drawing available at this site.

Using Genetic Algorithm as optimisation tool the pipe network is redesign as discussed in section-6.4. The recommended pipe sizes are found as given in table-6.8. After that the whole network is replaced by the new recommended pipe size. At all nodes the discharge and pressure are once again measured which was matched with table-6.1

**Figure- 6.4 Site Photographs of AIT Campus**

## 6.4 Application of Genetic Algorithm for AIT Pipe Network

### 6.4.1 Objective Function

The objective function of this pipe network is the minimisation of total cost. Neglecting the other factors, it is assumed that actual cost of the network is solely depending upon pipe size (commercially available, pipe diameter). To tackle the minimum head constraint and minimum discharge constraint, penalty cost is added to the actual cost of the network.

#### 6.4.1.1 The Network Cost

The network cost is calculated as the sum cost of all pipe in the network. Network cost is computed as follows:

$$\text{Network cost} = \sum_{i=1}^{N} C_i(D_i)L_i \quad (6.1)$$

Where $C_i(D_i)$ = cost per unit length of the $i^{th}$ pipe with diameter $D_i$, $L_i$ = length of the $i^{th}$ pipe and N = total number of pipes in the system.

#### 6.4.1.2 Penalty Cost

The penalty cost is superimposed on top of the actual cost of the network in such a way that it will discourage the search in the infeasible direction.

#### 6.4.1.3 Total Network Cost (z)

The objective function of this pipe network is the minimisation of total network cost:

$$\text{Total network cost (z)} = \sum_{i=1}^{N} C_i(D_i)L_i + \text{Penalty} \tag{6.2}$$

Subjected to:

$$\sum Q_{in} - \sum Q_{out} = Q_e \qquad \text{For all Nodes} \tag{6.3}$$

$$Q_{\min} \le Q_m \le Q_{\max} \qquad \text{For all Nodes} \tag{6.4}$$

$$H_m \ge H_{\text{m,min}} \qquad \text{For all Nodes} \tag{6.5}$$

Where $Q_{in}$ = flow into the junction; $Q_{out}$ = flow out of the junction; and $Q_e$ = external inflow or demand at the junction node, N is the number of pipe in network, m represent node number. $Q_m$ and $H_m$ represent the discharge and Pressure head required at nodes respectively. $Q_{\min}$ is the minimum and $Q_{\max}$ is the maximum discharge at any node. Similarly, $H_{\text{m,min}}$ is minimum pressure head required at any node m, L represent length of the pipe and $C_i$ represent cost function of pipe as shown in equation (6.1).

#### 6.4.1.4 Constraints

In practice it is difficult to find a penalty function which is an effective and efficient substitute for the constraints, (Section-3.2.9).The GA allocates a penalty cost for each demand pattern if a network does not fulfil the minimum pressure constraints. The maximum pressure deficit is multiplied by a penalty factor. Here, the value of penalty factor (K = 1/m) has been taken (Deb (2010)). The optimum solution lies on the boundary between feasible and infeasible solutions (Richardson et al. 1989).

### 6.4.2 Design Variables

Various design alternatives which relate to minimum cost of pipe network need to be considered to ensure that a good global optimal design is achieved. The decision variable (Parameters) for each pipe (pipe number [1], [2], [3], [4], [5] [6], [7], [8], [9], [10] and [11]) are its diameter as given in table-6.3.

**Table 6.3 Design Option for AIT Campus Pipe Network**

| Sl No. | Variables (Pipe Diameter) | Description of Variables Option (in mille-meter) | Total Number of Option |
|---|---|---|---|
| **1** | Pipe [1] as $x_1$ | 20, 25, 32, 40, 50, 65, 80, 100 | Eight (8) |
| **2** | Pipe [2] as $x_2$ | 20, 25, 32, 40, 50, 65, 80, 100 | Eight (8) |
| **3** | Pipe [3] as $x_3$ | 20, 25, 32, 40, 50, 65, 80, 100 | Eight (8) |
| **4** | Pipe [4] as $x_4$ | 20, 25, 32, 40, 50, 65, 80, 100 | Eight (8) |
| **5** | Pipe [5] as $x_5$ | 20, 25, 32, 40, 50, 65, 80, 100 | Eight (8) |
| **6** | Pipe [6] as $x_6$ | 20, 25, 32, 40, 50, 65, 80, 100 | Eight (8) |
| **7** | Pipe [7] as $x_7$ | 20, 25, 32, 40, 50, 65, 80, 100 | Eight (8) |
| **8** | Pipe [8] as $x_8$ | 20, 25, 32, 40, 50, 65, 80, 100 | Eight (8) |
| **9** | Pipe [9] as $x_8$ | 20, 25, 32, 40, 50, 65, 80, 100 | Eight (8) |
| **10** | Pipe [10] as $x_8$ | 20, 25, 32, 40, 50, 65, 80, 100 | Eight (8) |
| **11** | Pipe [11] as $x_8$ | 20, 25, 32, 40, 50, 65, 80, 100 | Eight (8) |

#### 6.4.2.1 Binary Coding for Commercially Available Pipes

In the GA formulation on test problem, eleven pipes were each represented by a three-bit binary substring. Three bit substring length were selected representing eight possible alternatives as shown in table-6.4. If commercially available pipe were more than eight numbers then, the length of substring can be increased. The binary coding for different pipes are taken arbitrary. E.g. - the binary coding for pipe 20 mm diameter has been taken (000) randomly and so on.

**Table 6.4 Options for Each Decision Variables**

| Sl No | Diameter of Pipe (mm) | Binary Coding |
|---|---|---|
| 1 | 20 | 000 |
| 2 | 25 | 001 |
| 3 | 32 | 010 |
| 4 | 40 | 011 |
| 5 | 50 | 100 |
| 6 | 65 | 101 |
| 7 | 80 | 110 |
| 8 | 100 | 111 |

Here, eleven different pipe sizes have to be optimized, then a binary substring of three bits can be used to represent the options for each of the eleven decision variables (see Table-6.4). A 33-bit binary string represents (as chromosomes) the network to be optimized made up of the eight by three-bit substrings for each decision variable. See Figure-6.4.

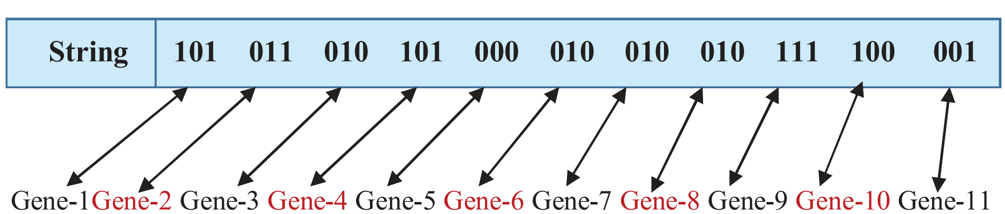


**Figure-6.5 String Structure**

### 6.4.3 Generation of Initial Population

The Genetic Algorithm (GA) generates the initial population of solutions (say, size n =100, see table-6.4) using a random number generator. Each bit location in the 33-bit string for this (case study) problem takes on a value of either 1 or 0. Each successive three bits represent a specific variables for the eleven pipes under consideration (i.e., for pipes [1], [2], [3], [4], [5], [6], [7], [8], [9], [10] and [11]). For example, if the 33 bits were **001 110 101 011 000 110 101 111 010 101 110**, then from Table-6.4 notation, the existing pipe pipes [1], [2], [3], [4], [5], [6], [7], [8], [9], [10] and [11] are used 25 mm, 80 mm, 65 mm, 40 mm, 20 mm, 80 mm, 65 mm, 100 mm, 32 mm, 65 mm and 80 mm respectively. The population size, which is typically a user-specified parameter, is one of the significant factors affecting the performance of genetic algorithms. For example, small population sizes might lead to premature convergence and yield substandard solutions. On the other hand, large population sizes causes to unnecessary spending of valuable computational time. The size of population size depend upon the complexity of problem.

**Table-6.5 Initial Solution (Population) Randomly Generated by GA**

| | |
|---|---|
| Chromosome-1 | 001 110 101 011 000 110 101 111 010 101 110 |
| Chromosome -2 | 111 100 101 001 101 100 001 100 011 000 101 |
| Chromosome -3 | 101 110 001 111 010 110 101 011 001 110 010 |
| … | … |
| … | … |
| Population-100 | 110 010 101 011 011 000 111 000 110 111 101 |

### 6.4.4 Hydraulic Analysis of Network

The actual heads are compared with the minimum allowable pressure heads and any pressure deficits are noted.

The constraints for demand patterns as shown below.

**a.** Continuity of flow equation i.e. the sum of inflow and outflow at all nine nodes (Node number as 2,3,4,5,6,7,8,9,10 in the network should be equal.

$\sum Q_m = \sum q_{m,n}$ where all node m= 2, 3….10

Where $Q_m$ is the discharge in pipe number i meeting at node m and $q_{m,n}$ is sum of all nodal (assume, n number of outlet at node m) withdrawal at node m.

**b.** The Hazen-Williams head loss equation for each pipe i connecting nodes j and k

$$H_j - H_k = \frac{-10.675\,L_i Q_i |Q_i|^{0.852}}{C_i^{1.852} D_i^{4.8704}}$$ For all pipes i=1, 2…….11

Where $L_i$ = Length of pipe, $Q_i$ = discharge inflow in pipe i and $C_i$ = Hazen Williams coefficient for pipe i.

**c.** Minimum Pressure head constraints ( $H_{min}$ ) at each nodes as shown in table-6.1

$H_m \geq H_{m,min}$ For all nodes m = 2 … 10

Here, $H_m$ is the pressure at any node m of network and $H_{m,min}$ is the minimum pressure required at any node.

**d.** Eleven new pipes (1, 2, 3, 4, 5, 6, 7, 8, 9, 10 and 11) are selected from the commercially available pipe as given in table-6.2.

### 6.4.5 Computation of Total Network Cost

Computation of total network cost , generation of new population and fixing of other parameters of GA have been done in similar way as stated in chapter-4, section-4.4.7, section-4.4.8, section-4.4.9, section-4.4.10 and section-4.4.11.

### 6.4.6 Computation of Network Cost Using Matlab Software

Pipe network optimisation is achieved by using Genetic Algorithm comprising reproduction, crossover and mutation. A software programming has been developed in MATLAB platform for getting optimal or near optimal solution for this case study.

**a.** The performance of the GA has been established to be heavily dependent on the parameter values. According to Tolson et al. (2009), the five parameters (population size, crossover point, and mutation rate, number of iteration and percentage of crossover) necessity to be tuned. Thus, it requires substantial effort, normally by trial and error, for practitioners to decide the most appropriate parameter values for GA in order to apply them to various optimisation problems. To establish GA's parameter values trial and error methods is considered.

**b.** In table-6.5, the population size (50), crossover point (single), and mutation rate (0.05) are kept constant and number of iterations and crossover percentage goes on changing. It is observed from convergence study (figure-6.5) that fitness value are very close at crossover percentage of 80% and 100%. Similarly, the fitness value at iteration rate 300 and 500 are very close. Crossover percentage as 80% and number of iteration as 300 have been selected for further convergence of fitness value.

**Table 6.6 Fitness Value (Total Cost in Rupees) Vs. Percentage of Crossover**

| Number of Iterations | Percentage of crossover | | | |
|---|---|---|---|---|
| | 20 | 50 | 80 | 100 |
| 50 | 171422 | 173623 | 160736 | 152838 |
| 100 | 178889 | 172769 | 152851 | 151212 |
| 200 | 171241 | 160736 | 152851 | 152851 |
| 300 | 170471 | 152343 | 150284 | 151212 |
| 500 | 156838 | 150284 | 150284 | 150284 |
| Note:- population size=50, Crossover point=1, Mutation rate=0.05 | | | | |

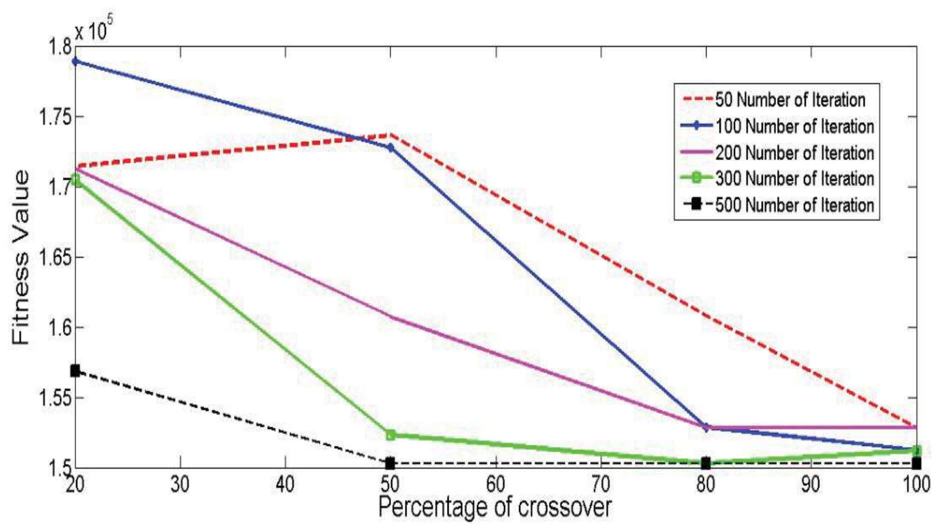


**Figure-6.6 Variation of Fitness Value vs. Percentage of Crossover**

**c.** In table-6.6, the number of iteration (300), crossover point (single), and percentage of crossover (80%) are kept constant and mutation rate as well as population size goes on changing. It is observed from convergence study (figure-6.6) that fitness value at population size at 300 and 500 are very close. Similarly, the fitness value at different mutation rate are very close. Population size as 300 and mutation rate as 0.05 have been selected for further convergence of fitness value.

**Table 6.7 Variation of Fitness Value (Total Cost in Rupees) at Different Mutation**

| Mutation Rate | Population Size | | | | |
|---|---|---|---|---|---|
| | 100 | 150 | 200 | 300 | 500 |
| 0.02 | 164508 | 154118 | 160736 | 152343 | 151212 |
| 0.05 | 171320 | 160736 | 152851 | 151212 | 152343 |
| 0.1 | 156648 | 156838 | 151212 | 150284 | 150284 |
| 0.5 | 156838 | 150284 | 151212 | 150284 | 150284 |
| Note:- Number of iteration=300, Crossover point=1, Percentage of crossover=0.8 | | | | | |

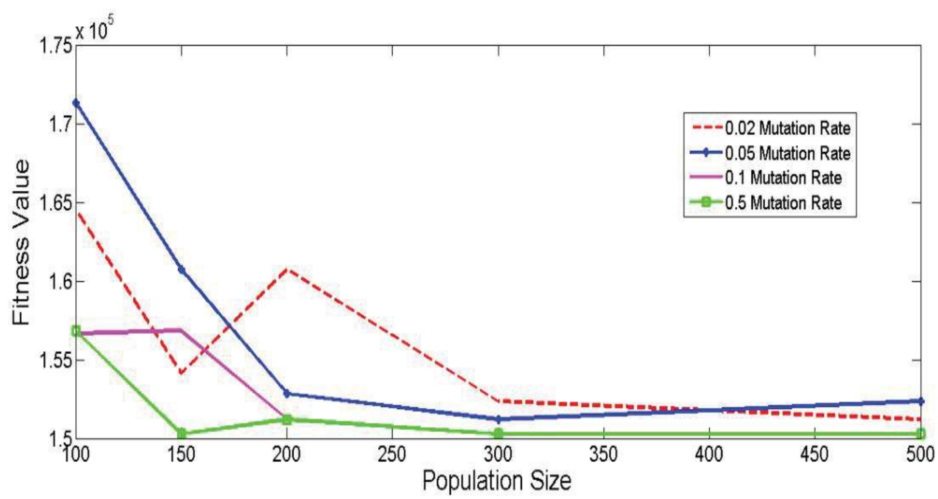


**Figure-6.7 Variation of Fitness Value vs. Mutation Rate**

**d.** In table-6.7, the fitness values are very close at one point, two point and three point crossover as shown in convergence study (figure-6.7). Here, single crossover point have been selected.

**Table 6.8 Fitness Value (Total Cost in Rupees) vs. Different Crossover point**

| Crossover Point | Population Size | |
|---|---|---|
| | **150** | **300** |
| **1-point** | 150284 | 150284 |
| **2-point** | 150284 | 150284 |
| **3-point** | 150284 | 150284 |
| Note:- Number of iteration=300, Percentage of crossover=0.8, Mutation Rate= 0.05 | | |

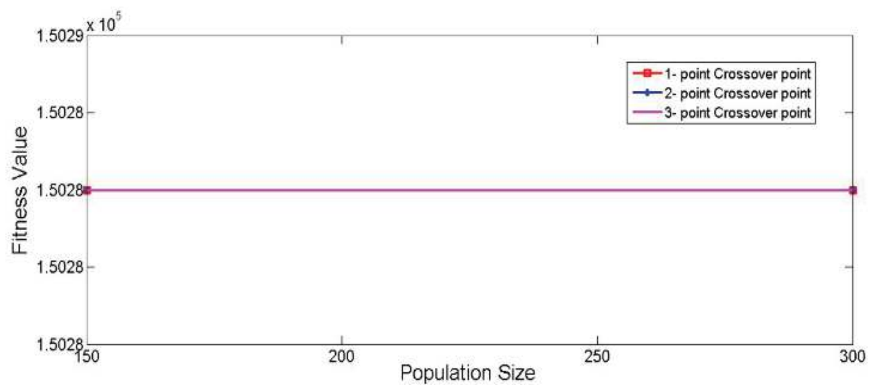


**Figure-6.8 Variation of Fitness Value vs. Crossover Point**

However, Population size (300), percentage of crossover (80%), number of iteration (300), mutation rate (0.05) and single point crossover have been selected to find the optimum value (minimum value) of network cost. The best solutions (total cost of network in Rupees) that satisfy all constraints are shown in figure-6.8. The optimum cost of the pipe network is Rupees **1, 50, 284** and the size of different pipes are given in the table-6.8.

**Table-6.9 Cost of the Pipe Network and the Diameter of Pipes in Millimetre**

| Cost (Rs) | Pipe [1] mm | Pipe [2] mm | Pipe [3] mm | Pipe [4] mm | Pipe [5] mm | Pipe [6] mm | Pipe [7] mm | Pipe [8] mm | Pipe [9] mm | Pipe [10] mm | Pipe [11] mm |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1,50,284 | 32 | 50 | 25 | 25 | 25 | 32 | 20 | 20 | 20 | 20 | 20 |

**Best Cost Results (Total Cost, Rs  1, 50,284 ) Shown in Graph**

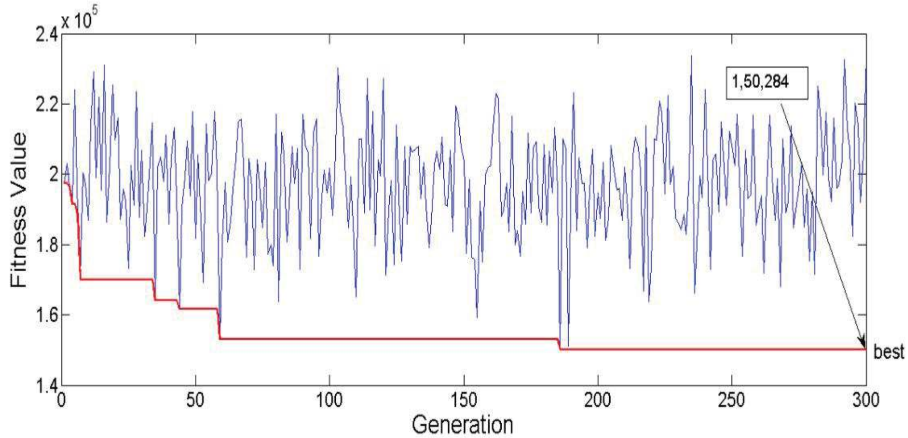


**Figure-6.9 Generation vs. Fitness Value (Best Cost Results)**

**Table-6.10 Existing Pipe in the Network VS.  Recommended New pipe**

| Sl. No. | Pipe Recommended | Existing Pipe |
|---|---|---|
| **1** | **32** | **65** |
| **2** | **50** | **65** |
| **3** | **25** | **40** |
| **4** | **25** | **40** |
| **5** | **25** | **40** |
| **6** | **32** | **40** |
| **7** | **20** | **40** |
| **8** | **20** | **40** |
| **9** | **20** | **40** |
| **10** | **20** | **40** |
| **11** | **20** | **40** |

The comparison of existing pipe and proposed pipe sizes are given in table-6.10

**Table-6.11 Comparison of Existing Pipe Network Cost and Proposed Pipe Network Cost at Present Market Rate**

| Sl No | Pipe Number | Pipe length (m) | Pipe size original (mm) | Rate of the pipe (Rs./m) | Cost of the Original pipe (Rs.) | Pipe Size Recommended (mm) | Rate of the pipe (Rs) | Cost of the Recommended pipe (Rs.) |
|---|---|---|---|---|---|---|---|---|
| **1** | 1 | 70 | 65 | 441.75 | 30922.5 | 32 | 226 | 15820 |
| **2** | 2 | 40 | 65 | 441.75 | 17670 | 50 | 350 | 14000 |
| **3** | 3 | 90 | 40 | 262.85 | 23656.5 | 25 | 176 | 15840 |
| **4** | 4 | 90 | 40 | 262.85 | 23656.5 | 25 | 176 | 15840 |
| **5** | 5 | 40 | 40 | 262.85 | 10514 | 25 | 176 | 7040 |
| **6** | 6 | 90 | 40 | 262.85 | 23656.5 | 32 | 226 | 20340 |
| **7** | 7 | 90 | 40 | 262.85 | 23656.5 | 20 | 120.4 | 10836 |
| **8** | 8 | 40 | 40 | 262.85 | 10514 | 20 | 120.4 | 4816 |
| **9** | 9 | 90 | 40 | 262.85 | 23656.5 | 20 | 120.4 | 10836 |
| **10** | 10 | 90 | 40 | 262.85 | 23656.5 | 20 | 120.4 | 10836 |
| **11** | 11 | 200 | 40 | 262.85 | 52570 | 20 | 120.4 | 24080 |
| | | | Total Old Cost (Rs) | | **264129.5** | Total Recommended Cost (Rs) | | **150284** |

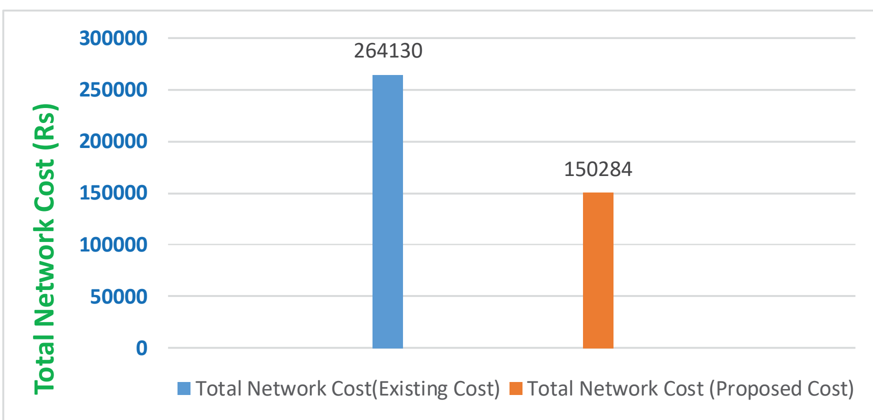


**Figure-6.10 Cost Comparison Chart (Existing pipe network Vs. Proposed pipe network)**

## 6.5 Results and Discussion

From table-6.9 and table-6.10, it is clear that the total cost (based on GA) of given pipe network is much less as compared to the existing cost of pipe network. It should be noted here that (in GA analysis) pressure and discharge at all nodes are meeting the requirement as per table-6.1. This is clearly indicating that computational code (in the form of table/charts) developed here for optimisation of pipe network design is working efficiently and effectively.