A
Dissertation Report
On

OPTIMIZATION OF SEWER NETWORK USING GENETIC ALGORITHM

By
PRASHANT GANDHI
Environmental Engineering
2014PCE5412

Submitted In the partial fulfilment for the Award of degree of
Masters of Technology in Environmental Engineering

DEPARTMENT OF CIVIL ENGINEERING
MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY
JAIPUR-302017
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Under the Supervision of
Dr. Y.P. Mathur
Professor, Department of Civil Engineering

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Dedicated to My Parents

DEPARTMENT OF CIVIL ENGINEERING
MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY
JAIPUR, RAJASTHAN-302017

CERTIFICATE

This is to certify that the dissertation report on **“OPTIMIZATION OF SEWER NETWORK USING GENETIC ALGORITHM”** which is being submitted by **Prashant Gandhi** (2014PCE5412), in the partial fulfillment for the **Master of Technology** in **Environmental Engineering** to the Malaviya National Institute of Technology, Jaipur. The dissertation work has been completed under my guidance and supervision. The work is approved for submission.

Place:
Date:

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DATE: **PRASHANT GANDHI**

ABSTRACT

A sewerage system is a closed underground conduit which carries the sewage from house to treatment plant. Sewer networks are an essential part of the infrastructure of any society. Due to a rapid increase in the population and the corresponding increase in load of sewerage system make it necessary to design the sewer network properly and as it is the basic need for every individual hence cost optimization is very important for better service. Since, the investment required for construction and maintenance of these large scale networks is so huge and, thus any reduction in the cost of these networks may result in considerable reduction of total construction cost.

Without using the concept of optimization, the design is simply based on the idea of keeping pipe slopes as flat as possible, giving a feasible but over-expensive solution. Optimal sewer design aims to minimize the network construction cost whilst ensuring a good system performance. More recently, a significant amount of research has focused on the optimal design or upgrade of the sewerage system. Some of the earlier studies uses linear programming, while later studies applied nonlinear programming, dynamic programming or a heuristic approach. ACO and PSO also gained much popularity in optimizing the design of sewerage systems. However, much of the recent literature has utilized Genetic Algorithms for the determination of low-cost sewerage system designs and they have been shown to have several advantages over more traditional optimization methods.

The objective of this thesis is to show that the genetic algorithm can be used successfully in the design of sewerage system to minimize the overall cost of the system. In this thesis, a new and powerful intelligent evolution method, called genetic algorithm (GA) is adopted for solving the optimization problem. The proposed method was searched algorithms based on the mechanics of natural selection and natural genetics. Genetic Algorithms are part of evolutionary computing. Genetic Algorithms are the heuristic search and optimization techniques that mimic the process of natural evolution.

In this research, a new algorithm for GA has been proposed. The proposed algorithm is coded using FORTRAN. Then, GA algorithm has been applied to the design of sewerage system through the optimization of the objective function. The performance of a hypothetical case has been evaluated using FORTRAN to test the effectiveness and validity of the proposed algorithm. The GA tool in FORTRAN is used to find the optimal cast of the sewerage system. The obtained results show that the proposed method is promising in the optimal design of the sewerage system.

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LIST OF SYMBOLS

A = Area of Flow (m^2)

a = Cross Sectional Area (m^2)

AVG = Average of Depth of Excavation (m)

CC = Concrete Cover (m)

CK = Constant K

C_{min} = Minimum Cover (m)

COSTEX = Cost of Excavation (₹)

COSTMH = Cost of Manhole (₹)

COSTSW = Cost of Sewer (₹)

D = Diameter of the Sewer (m)

DEP_EX = Depth of Excavation (m)

DEPMAX = Maximum Depth of Excavation (m)

DEPTHE = Downstream Depth (m)

DEPTHS = Upstream Depth (m)

D_{min} = Minimum Diameter (m)

d_p = Particle Size (m)

DR = Depth Ratio

DS = Downstream

ERW = Earthwork

Gen = No. of Generation

GRLE = Ending Ground Level (m)

GRLS = Starting Ground Level (m)

HMD = Hydraulic Mean Depth (m)

idum = Initial random no. seed for GA run

ILDS = Downstream Invert Level (m)

ILUS = Upstream Invert Level (m)

indmax = Maximum of individuals

LINEL = Length of Sewer (m)

maxgen = Maximum no. of generations to run by GA

n = Manning Coefficient of Roughness

nchrmax = Maximum of chromosomes per individuals

nparam = No. of parameter of each individual

nparamax = Maximum of parameters which chromosomes make up

npopsiz = Population size of GA run

P = Wetted Perimeter (m)

PC = Total Penalty (₹)

pcross = Crossover probability

PEN = Penalty (₹)

PENDEP = Penalty due to Depth (₹)

PENVMAX = Penalty due to Maximum Velocity (₹)

PENVMIN = Penalty due to Minimum Velocity (₹)

pmutate = Jump mutation probability

PVMAX = Maximum Velocity (m/sec)

Q = Discharge (m^3/sec)

r = Hydraulic Mean Radius (m)

S = Slope of Sewer (m/m)

SDD= Total length of the sewer

SMH = Sum of No. Of Manhole

S_r = Required Slope

S_s = Specific weight of Suspended Solids

TCOST = Total Cost of Sewer (₹)

UCSW = Cost of different diameters of pipes

US = Upstream

V = Velocity (m/sec)

V_{max} = Maximum Velocity (m/sec)

V_{min} = Minimum Velocity (m/sec)

ABBREVIATIONS

ACO = Ant Colony Optimization
BAM = Benefit Assessment Model
CA-GASiNO = Cellular Automata and Genetic Algorithm for Sewer in Network Optimization
CSM = Collection System Model
DP = Dynamic Programming
DSS = Decision Support System
GA = Genetic Algorithm
LP = Linear Programming
MOGA = Multi Objective Genetic Algorithm
PSO = Particle Swarm Optimization
SSD = Sanitary Sewer Design
SSOM = System Optimization Model
TSM = Transportation System Model

1. INTRODUCTION

1.1 Background

A sewer system is an underground carriage system, which uses gravity to collect and transport sewage from houses and commercial buildings to sewage treatment plant or at the point of discharge into the environment. A sewer system is a network of sewer pipes, connecting the manholes, pumping stations and other appurtenances.

Due to a rapid increase in the population and the corresponding increase in the load of the sewerage system, performance of pollution control laws and increasing awareness towards sanitation, the problem of waste water collection and disposal i.e. becoming a major concern today. The cost of a sewage collection system is a major fraction of the overall cost of waste disposal. Thus, money can be saved by improving sewerage system design.

Its concept was first proposed in the mid-1960s when advances in the computer power shined a light on engineering research. Comprehensive, cost-effective designs including early simulation models and optimization technologies became computationally tractable and flourished in the 1970s and 1980s. Various early optimization techniques were developed, such as Linear Programming (LP) (Deininger, 1966; Dajani and Hasit, 1974), Nonlinear Programming (NLP) (Holland, 1966; Price, 1978), and Dynamic Programming (DP) (Mays and Yen, 1975; Walters and Templeman, 1979).

The design of a sewer system may be divided into two phases:

1. The selection of the network layout (topological sorting); and
2. The hydraulic design of the sewer pipes for the selected layout (in this determine the discharge rates, the pipe diameters, the slopes, and invert elevations) (Tekeli and Belkaya, 1986).

The design of a sewerage system involves selection of a suitable combination of pipe diameters and slopes so as to ensure adequate capacity for peak flows and sufficient self cleansing velocities at minimum flow.

Designers typically use charts and specific rules to determine the diameters, slope and materials of sewers when designing sewer networks.

Suitable diameters and slope combinations are selected for all the pipes between all the manholes so that the wastewater can be conveyed without violating any hydraulic constraints. Since there is an extensive range of diameters, pipe slopes and coefficients in the hydraulic relationships, designers usually can only evaluate a small number of networks that do not violate any of the constraints..(Liang et al. 2000)

The outcome of such a procedure depends on to a large extent on the designer experience and efforts. It is practically almost impossible to incorporate all feasible design alternatives, and an optimal solution is not necessarily reached. Only a resources to computer oriented optimal designing may be a solution.

1.2 Present Work

The waste water collection system considered in the present investigation incorporates only gravity collection main. The optimization of such a system constitutes minimization of a nonlinear cost function subject to various constraints. Many of the constraints too, are of non-linear nature.

In this Genetic Algorithm is used for the optimization. Genetic Algorithms (GAs) begin, just like many other optimization algorithms, by defining the cost function and optimization parameters. They also terminate like other optimization algorithms, by testing for convergence (Guo et al. 2008). Genetic Algorithms have been developed by John Holland, his colleagues, and his students at the University of Michigan.

1.3 Objective of the Study

The objective of this study is to design an optimal sewer network and to find a cost-effective solution that minimizes capital investment while ensuring a better system performance under specific design criteria. This report basically provides a detailed method of implementing a recently proposed optimization technique, named Genetic Algorithm on sewer networks.

The purpose of this study is to describe the development and application of a genetic algorithm for the least-cost design and operation of the sewer system. This report basically provides a detailed method of implementing Genetic Algorithm technique on sewer system networks. The proposed algorithm is coded using FORTRAN. This study also shows that the genetic algorithm can reduce the costs and to enhance the performance of networks.

1.4 Overview of the Report

The report has been prepared with an objective to provide a detailed description of the application of the genetic algorithm to sewer systems. A hypothetical case study was considered for the application of proposed algorithm.

In Chapter 2, a review of different optimization techniques for sewerage systems and genetic algorithm are presented.

In Chapter 3, a brief description about the sewerage system, its components and types are presented. Besides these, the hydraulic principles to be considered in a sewer system network are also mentioned.

In Chapter 4, a detailed description of Genetic Algorithm technique for better understanding has been provided along with an example.

In Chapter 5, the optimization problem is formulated as a single objective optimization problem with equality and inequality constraints to be followed.

In Chapter 6, a computer program to solve the optimization problem using the proposed method and the methodology for application of the genetic algorithm to the sample network has been discussed.

In Chapter 7, the input data and results obtained from the proposed optimization method are presented along with a sensitivity analysis of total cost.

And finally, the conclusions are presented in Chapter 8.

2. LITERATURE REVIEW

The design of a sewerage system, in general, involves selection of a suitable combination of pipe sizes and slopes so as to ensure adequate capacity for peak flows and adequate self cleansing velocities at minimum flow. In a conventional design procedure, efforts are made to analyze several alternative systems (each meeting the physical and hydraulic requirements), and the least cost system is selected. Obviously, the outcome of such a procedure depends on a large extent on the designer experience and efforts. Notwithstanding sincere efforts on the part of designer, it is practically almost impossible to incorporate all feasible design alternatives, and an optimal solution is not necessarily achieved. Only a resources to computer oriented optimal designing may be a solution.

Sewerage mainly involves the major portion of the cost of a wastewater system. In the design of a sewerage system, the sewer line is the basic unit repeatedly occurring in the design process. Any savings in the cost during the design of this unit will reduce the overall cost of the sewerage system. (Swamee, 2001)

In order to achieve this goal, designer depends on cost optimization techniques.

Constraints which are appearing in the literature for optimal sewer design are presented below:

- A minimum velocity constraint prevents settlement of sediments.
- A minimum pipe slope avoids adverse slopes caused by inaccurate construction or settlement.
- A minimum top cover constraint level protects buried pipes from surface damage.
- A minimum pipe size is selected based on experience.
- The crown level of a pipe leaving a manhole is not should be higher than those of entering pipes.
- The pipe leaving a manhole has a diameter at least as big as any pipe entering. This is to avoid physical blockage.

2.1 Optimization Methods for Sewer System

Several optimization methods have been proposed to solve the optimal solution problem for sewer systems. Without any concept of optimization, the design is only based on the idea of keeping pipe slopes as flat as possible, giving a feasible but over-expensive solution (Guo et al. 2008). Optimal sewer design aims to minimize the network construction cost while ensuring a good system performance. A brief review of many of the optimization techniques has been presented below.

A survey of the literature showed that the current status of sewer line design algorithms uses linear programming and dynamic programming. The linear programming which uses piecewise linearization of the objective function and constraints in every cycle, requires substantial computer time. On the other side, dynamic programming algorithms require large amounts of computer memory. (Swamee, 2001)

Researchers have been investigating the cost of efficient sewer system with various approaches such as linear, dynamic, and heuristic programming.

2.1.1 Dynamic Programming

Dynamic programming can only be applied if the complex problems with a large number of variables are decomposed into a series of sub-problems, which solve recursively. Large sewerage systems may be decomposed to small subsystems, which are optimized internally, and later recombined to a single optimal network. (Argaman et al. 1973)

DP and its modified version Discrete Differential Dynamic Programming (DDDP) were popularly applied techniques, and DDDP is still well-liked in some current studies. (Mays and Wenzel, 1975)

Walters (1985) considered the sewers diameters, nodes layout, diameters, and slopes as decision variables using dynamic programming for the least cost design of sewer networks. Dynamic programming is a technique well suited for the optimization of a multistage decision problem where decision are to be made sequentially at different points and different levels (Merritt and Bogan, 1973).

DP methods are the first and most used method for optimal design of storm sewer networks due to the following features of these networks. Robinson and Labadie (1981), Kulkarni and Khanna (1985), and Li and Matthew (1990) employed DP to design wastewater and storm water networks optimally.

Rashid and Hayes (2010) developed a simple but effective approach. They Objectively selected and prioritized sewerage projects on the basis of dynamic programming (DP), within available funds and system capacity., The problem was formulated as three dynamic programming models; a collection system model (CSM), a transportation system model (TSM), and a benefit assessment model (BAM). The optimum sewerage plans were obtained in two steps. First, potential collection areas were identified and selected by the CSM. Then, the TSM was utilized to identify the optimum routes to a treatment plant for wastewater conveyance for these selected areas. Depending upon the available funds and treatment system capacities, some areas selected by the CSM were discarded by the TSM.

2.1.2 Linear Programming

Linear programming is a very powerful and easy-to-use form of optimization and is most efficient for problems that can be expressed in linear terms. For sewer network control, linear programming is used in for the development of a control algorithm (Bradford, 1977). There have been some efforts using the Linear Programming method to solve the problem of sewer network design, like Deininger (1970), Dajani and Gemmell (1971), Froise and Burges (1978), and Walters and Templeman (1979).

Deininger (1970) formulated a method of solution for a gravity flow sewer system by proposing an objective function of two variables - depth to subgrade and the pipe diameter.

Dajani et al. (1971) used a convex-separable linear objective function. The objective function is based on development by Holland (1966) for the design of gravity flow sewer systems. The objective function is a nonlinear function of two variables - the sum and difference of the upstream and, downstream elevation of each sewer. With this formulation, all the constraints are linear with respect to the two variables. Thus, the problem is to minimize a nonlinear objective function subject to linear constraints. The technique used to solve this is called convex separable programming.

LP is a unique form of mathematical programming. It can easily handle a large number of decision variables and implement the optimization in an efficient, reliable and deterministic manner (Guo et al., 2008). This approach poses several requirements for its implementation:

(i) All objective functions and constraints should be linear. However, highly dynamic hydraulic conditions are barely possible to have a linear relationship with decision variables, such as pipe diameters and slopes.

(ii) All decision variables are considered as continuous variables. Its results often encompass continuous diameters, which have to be adjusted by rounding each continuous diameter up to its nearest commercial size.

(iii) LP needs individual segments of the problem to operate as well independently as together. For this purpose each pipe to be designed separately. That implies every pipe flow is independent of flows in adjacent pipes, which, even for a tree-like network, is only true in a steady state condition. (Walters, 1979)

2.1.3 Non-Linear Programming

Nonlinear programming offers a more general mathematical formulation than linear and dynamic programming and can effectively handle nonlinear objective functions and nonlinear constraints. Gupta et al. (1976), Lemieux et al. (1976), and Price (1978) applied NLP to yield optimal sewer network.

Gupta et al. (1976) developed a methodology to deal with depth and diameter optimization. The problem is to minimize a non-linear cost function subject to a set of non-linear constraints. They employed a nonlinear programming based on interior penalty function method coupled with Powell’s method of conjugate directions. Each link was considered in sequence, and the objective function was minimized subject to six constraints.

A methodology is developed to design a storm water sewer system using a nonlinear programming approach. It is divided into five steps: (1) hydrology, (2) set up of the technological constraints, (3) optimization with the Rosen's projected gradient method with the pipe diameters considered as continuous variables, (4) standardization of the diameters, and (5) post-optimal analysis of the piezometric surface. The purchase, installation and the excavation costs of every pipe included in the cost function. It is a convex programming problem. Therefore, the minimum solution is an absolute minimum (Lemieux et al., 1976).

2.1.4 Heuristic Methods

Liebman (1967) suggested a heuristic method for optimizing the sewer layout, assuming the pipe diameters to be fixed. The best layout is found by a search procedure. At each step, one “branch” of the network is changed. The change is retained if it results in a decrease in the cost.

Desher et al. (1986) developed a heuristic program for the design of the entire network using Manning's hydraulic equation. Their heuristic program, titled Sanitary Sewer Design (SSD), is programmed in BASIC language on an Apple II microcomputer. SSD expects the designer to specify pipe diameters; it will then calculate pipe slopes, velocities, and depth of flow, select invert elevations, and estimate the cost of the network.

Charalambous et al. (1990) present a heuristic approach for the design of sewer networks, which can control the introduction of lift stations and the use of standard diameters. This heuristic approach provides good and logical (rather than optimal) designs of sewer networks. The heuristic approach presented in this paper aims at determining the upstream and downstream elevations and diameter to minimize the total excavation of the sewer network.

2.1.5 Particle Swarm Optimization (PSO)

The Particle Swarm Optimization (PSO) algorithm, as one of the latest algorithms inspired from nature, was introduced in the mid-1990s and since then, it has been utilized as an optimization tool in various applications. PSO is developed by Dr. Eberhart and Dr. Kennedy in 1995, which is inspired by social behavior of bird flocking or fish schooling, a population-based stochastic optimization technique (Kennedy and Eberhart, 1995).

PSO shares a lot of similarities with evolutionary optimization techniques like Genetic Algorithms (GA). The system is initialized with a population of random solutions and searches for an optimum solution by updating generations. Nevertheless, PSO has no evolution operators such as crossover and mutation like GA. In PSO, the potential solutions, called particles, fly within the search space by following the current optimum particles. (Lovbjerg and Krink, 2002).

Izquierdo et al. (2008) take an example of a wastewater collection network to show the performance, and the obtained results of PSO algorithm are compared with those given by using dynamic programming to solve the same problem under the same conditions. The decision variables are pipe diameters and slopes. While slopes are clearly continuous variables, diameters treated as discrete. Another continuous variable is the depth of excavation. PSO is applied to the cost function. After the result comparison, it is concluded that PSO is better than dynamic programming.

Each particle keeps track of its coordinates in the problem space which is associated with the best solution (fitness) it has reached so far. (The fitness value is also stored.) This value is called *pbest*. Another "best" value that is tracked by the particle swarm optimizer is the best value, obtained so far by any particle in the neighbour of the particle. This location is called *lbest*. When a particle takes all the population as its topological neighbors, the best value is a global best and is called *gbest*. (Chen et al., 2010)

The concept of particle swarm optimization consists of, at each time step, varying the velocity of (accelerating) each particle toward its p*best* and *lbest* locations in search space (local version of PSO). Acceleration is weighted by a random term, with separate random numbers being generated for acceleration toward *pbest* and *lbest* locations. (Roy, 2012)

A new modification in the sewer design with PSO is that we can generate a different layout for the same area network. And this is done by choosing the beat combination of minimum discharge and minimum length travel. (Navin and Mathur, 2016)

In past several years, In many research and application areas PSO has been applied successfully. PSO provides better results in a cheaper, faster way compared with other methods. Another reason that PSO is appealing is that there are few parameters to modify. Just by making slight variations in one version, works in a wide range of application.

2.1.6 Ant Colony Optimization (ACO)

The ant colony optimization algorithm is a probabilistic technique for the purpose of solving computational problems. Initially, the algorithm was aiming to search for an optimal path in a graph. Originally proposed by Marco Dorigo in 1992 in his Ph.D. thesis, based on the behavior of ants seeking a path between a source of food and their colony. The original idea has since diversified to solve a wider class of numerical problems, and as a result, several problems have emerged, drawing on various aspects of the behavior of ants.

Ant colony optimization algorithms are basically designed for discrete optimization problems in which the value of the decision variable is to be selected from a discrete set of possible values. Application of these algorithms to continuous optimization problems requires the transformation of the continuous search space to a discrete space by discretization of the continuous decision variables. In this procedure, the allowable continuous range of decision variables is discretized into a discrete set of allowable values and then a search conducted over the resulting discrete search space for the optimum solution (Abbaspour et al. 2001; Vitkovsky et al. 2000)

2.2 Genetic Algorithm

Genetic algorithms (GA) is an efficient technique for finding near exact solutions to a wide range of complex optimization problems. GA is based on the mechanics of natural genetics (Holland, 1975). They can search large solutions spaces quickly and only require an objective function to be specified. Recently, GA has been used in the optimization of wastewater collection systems.

Liang et al. (2000) use Genetic Algorithms (GA) to identify good feasible pipeline networks. First gravity wastewater collection pipelines designed. To find the optimal cost, constraints must be satisfied the gravity wastewater collection system. Then GA is used to find the optimal solution.

Liang et al. describes the development and application of a GA using a repair procedure to incorporate the many constraints involved designing a large gravity wastewater collection system.

Liang et al. (2004) implemented genetic algorithms and tabu search techniques to solve the optimization problem. Specialized procedures were developed for improving the efficiency of both techniques. An adaptive rule was constructed for ensuring that diameter progression constraints were satisfied for the GA. A dynamic search strategy was implemented for the TS that allowed a more diverse range of solutions to be explored to avoid premature convergence. Both procedures were able to improve the performance of the meta-heuristic techniques.

Weng and Liaw (2005) first used a genetic algorithm (GA) to establish a combinatorial optimization model. They called it the Sewer System Optimization Model for Layout & Hydraulics (GA/SSOM/LH). This model finds an optimal design for a real urban sewer system. The problems of “network layout” and “hydraulic design” optimization are handled simultaneously. GA and Sewerage System Optimization model (SSOM) used to generate possible network layouts as well as to develop a "hydraulic design" optimization module, which can find the best sewer system layout in between several possible alternate network layouts layout by checking the overall least-cost hydraulic design.

Afshar (2006) developed a genetic algorithm for the optimal design of stormwater networks. The nodal elevations of the sewer network are considered as the decision variables. A steady state simulation code is applied to analyze the trial solutions provided by the GA optimizer.

Guo et al. (2006) introduce a robust hybrid optimization method, named CA-GASiNO (Cellular Automata and Genetic Algorithms for Sewers in Network Optimization). This is performed in two stages. Cellular Automata (CA) principles are firstly applied to achieve a set of preliminary solutions, which are utilized to seed a Multi-objective Genetic Algorithm (MOGA) at the second stage for final polished designs. The CA-based approach generates a good initial population at a minuscule computational cost and hence saves from the computation for the following genetic algorithm runs. The GA targets the global optimal which is fundamentally troublesome to the localized CA approach.

Boomgaard et al. (2001) discuss the potential of the use of genetic algorithms for optimization of wastewater systems. The definition of the objective function and also the characteristics of the GA, especially mutation probability, proved to be key elements for a successful application of a GA for this kind of problems. Finally, it is concluded that GAs are capable of solving the very complex optimization problems related to the improvement of total wastewater systems.

Halfawy et al. (2008) discuss the application of the proposed approach to implementing a GIS-based Decision Support System (DSS) to support the renewal planning of sewer networks. A genetic algorithm-based multi-objective optimization technique is used to find a feasible solution, each comprising a set of sewers to be renewed annually, along with the associated costs and expected benefits in terms of condition improvement and risk reduction.

Pan and Kao (2009) used GA-QP Model to design the optimal design of sewer. A set of diameters for all pipe segments in a sewer system is taken into account as a chromosome for the proposed GA model. The system cost, pipe slopes, and pipe buried depths of every generated chromosome are determined using the QP model.

Brand and Ostfeld (2011) describes the application of a genetic algorithm model for the optimal design of regional wastewater systems comprised sewer pipelines, treatment plants, and end users of renovated wastewater. The algorithm seeks the diameter size of the designed pipelines and their flow distribution at the same time, the number of treatment plants and their size and location, the pump power, and also the required excavation work.

3. SEWERAGE SYSTEM

The underground conduit for the collection of sewage is called sewer. A sewer system uses gravity to collect and transport sewage from house to sewage treatment plants through a network of hydraulically designed sewer pipes, connecting the sewer pipe network, manholes, pumping stations and other related appurtenances.A sewerage system cannot only be a basic facility for draining waste water to protect the environment and public water bodies but also contributes to the restoration of the water environment.

Sewerage system offers important advantages and interesting possibilities for sustainable development under the idea of sustainability. A sewerage system cannot only be a basic facility for draining waste water but also contributes to the restoration of the water environment for maintaining the healthy social water cycle. (Zhang, 2011)

The most fundamental role of Sewerage Systems is Immediate Removal of Wastewater. If the wastewater generated by human activities is not removed and remains near a residential area, Public Hygiene will not be well maintained, and the living condition will become unpleasant. By promotion of sewerage systems, wastewater is removed immediately, and surrounding environment is significantly improved.

One of the important roles of sewerage systems is Drainage of rainwater in urban area and prevention of flooding. In recent year, mainly because of the advancement of urbanization, rainwater permeable area has decreased by increasing of construction of buildings and houses, roads area etc. As a result, stormwater runoff amount has increased, resulting in increased occurrence of flooding.

3.1 Types of Sewerage System

Different types of sewerage systems are classified on the basis of carrying water and technology used. These are described below:

3.1.1 On The Basis of Carrying Water

3.1.1.1 Sanitary Sewerage System

This system is designed to receive domestic sewage and industrial waste excluding stormwater. This system is composed of various sewer lines which are ends at the junction of a large sewer line. The large sewer line also ends at the junction of a larger sewer line. At last, the main sewer line terminates at the outfall. This system carries the sediments to the treatment plants, where it can be removed. (Swamee, 2001)

3.1.1.2 Storm Sewerage System

This carries rainwater which comes from paved roof areas, pavements and roads. Storm water sewers are usually larger than sanitary sewer systems because they are designed to carry much larger amounts of water. For reducing the unnecessary overloading in sewage treatment plant and avoiding the variation of flow, these two systems, sanitary and storm sewer are used separately. In storm sewerage system, sediments are mainly inorganic and non-cohesive.

3.1.1.3 Combined Sewerage System

This system carries both domestic water and storm water. During wet weather, the combined volume of wastewater and stormwater runoff entering in sewerage system often exceeds conveyance capacity. Due to this reason, combined sewerage system was designed to overflow occasionally and discharge excess water directly into the nearby stream, river or water bodies.

3.1.2 On The Basis of Technology Used

3.1.2.1 Conventional Sewerage System

Conventional sewer system is used to carry the wastewater from house to the treatment plant. These are used in an urban area with consistently sloping ground and these are used in the city. These are not very good for the hilly or flat areas because it requires deep excavations. These are also not suitable for the areas where the water level is high. In conventional sewerage system, the human excreta is diluted with flushing water, mixed with other water and finally treated.

3.1.2.2 **Simplified Sewerage System**

Simplified sewerage is an off-site sanitation technology that separates all wastewater from the household environment. This system was basically developed for low-income areas and where there is an insufficient space problem for the onsite system. Simplified sewerage system is reliable, upgradeable and extendable. It is applicable in all situations, but it is suitable for areas which are characterized by gently sloping topography, a high and low-density population with reasonably water supply, small homesteads with the scarcity of space, high water table, impervious soil and shallow bedrock. These sewer systems are cost effective at lower densities than the other (Mara, 2008).

This system was first implemented in Brazil (Bakalian et al. 1994). It is also successfully used in rural areas such as in the north-eastern Brazilian state of Ceara (Sarmento, 2001). This system has also been employed in some other Latin American countries (Bolivia and Peru) and some Asian countries (Pakistan and Sri Lanka) (Sinnatamby et al. 1986). In India, there is only one place (Ramagundam in Karimnagar district of Andhra Pradesh) where this system is being tried (Nema).

3.1.2.3 **Small Bore Sewerage System**

This system is designed to receive only the liquid portion of the household wastewater for offsite treatment and disposal. This system cannot handle commercial waste water with high grit or settleable solids levels. Odor is the most common problem in these systems.

3.2 Sewer Appurtenances

The various accessories on the sewerage system, which are essential for the efficient operation of the system are called sewer appurtenances. They include manholes, lamp holes, inverted siphons, and so on.

3.2.1 Manholes

A manhole is an opening which is constructed on the alignment of a sewer for facilitating a person access to the sewer for the purpose of inspection, testing, cleaning and removal of obstructions from the sewer line.

Manholes are the openings of either circular or rectangular in shape. They serve as ventilators for sewers, by the provisions of perforated manhole covers. Also, manholes facilitate the laying of sewer lines in convenient length.

Manholes are provided at all junctions of two or more sewers, whenever diameter of sewer changes, whenever the direction of sewer line changes and when sewers of different elevations join together.

3.2.2 Lamp holes

Lamp holes are the verticle pipe or shaft extending from the surface of the ground to a sewer line between two manholes which are far apart. A light (or lamp) may be lowered down the sewer line for the purpose to inspecting or find out any obstruction inside the sewers from the next manhole. Rarely constructed today.

3.2.3 Inverted siphons

Inverted siphons (also called depressed sewers) enable stormwater or wastewater sewers to pass under obstacle like rivers. Unlike the main sewer pipe(Gravity flow), the siphon pipes flow under pressure and must have flow velocities greater than 0.9 m/s for sewage to keep material suspended(Metcalf & Eddy 1981). Therefore, some siphons having smaller diameters than the main sewer may be required. The calculation computes siphon diameters (or siphon flows), velocities, inlet chamber wall heights, and siphon invert elevations.

3.2.4 Pumping of Sewage

Pumping of sewage is required when it is not possible to have a gravitational flow for the entire sewerage project.

3.2.5 Measuring Devices

The suitable flow measuring devices can be installed at different locations in a sewerage system.

3.3 Design Considerations

3.3.1 Introduction

Many design & construction factors need to be considered before sewer design can be completed. Factors such as design period, peak, average and minimum flows; sewer slopes and minimum and maximum velocities; design equations; sewer material; joints and connections, appurtenances, and sewer installation; etc., are all important in developing sewer design. The manual on sewerage and sewage treatment (1993) contains recommendations and guidelines on these factors based on practical considerations. Manual on Sewerage and Sewage Treatment published by Central Public Health and Environmental Eng. Organization, Ministry of Urban Development, New Delhi, Edition, 1995. Some of the basic factors, used in the present work, are briefly discussed below.

3.3.2 Design Period

The length of time up to which capacity of sewer will be adequate is referred to as design period. Generally, a design period of 30 years (excluding construction period) is recommended for all types of sewer

3.3.3 Flow Assumptions

The flow discharge in sewers varies considerably from hour to hour and also seasonally but for the purpose of hydraulic design, it is the estimated peak flow that is adopted since it is both difficult and uneconomical to augment the capacity of the sewer system at a later date. The peak factor is the ratio of maximum to average flows, depends on the contributory population.

Table 3.1: Recommended Values of Peak Factors

Contributory Population	Peak Factors
Up to 20,000	3.00
20,000 to 50,000	2.50
50,000 to 7,50,000	2.25
Above 7,50,000	2.00

(Source: Manual on Sewerage and Sewage Treatment, 1993)

3.3.4 Per capital Sewage flow

Although the entire spent water of a community should contribute to the total flow in a sanitary sewer, a small portion may be lost in evaporation, seepage in ground, leakage etc. In some arid areas the fraction reaching the sewers may be as low as 40% while for an intensely developed area, it may be high as 90%. Generally, 80% of the water supply may be expected to reach the sewers unless there is data available to the contrary.

3.3.5 Self-Cleansing Velocity

The sewage flowing through a sewer contains organic and inorganic matter which remains suspended in the sewage. To make the solid matter in suspended form, a certain minimum velocity of flow is required; otherwise, they will settle in the sewer, resulting in its clogging. Such minimum velocity is known as "self cleansing velocity."

Self considering the velocity (V) is determined by considered the particle size (d_p) and the specific weight (S_S) of suspended solids in sewage. This may be calculated by Shields' formula:-

$$V = \sqrt{g.(S_S - 1).d_p} \quad \text{(3 to 4.5 m/s)} \qquad (3.1)$$

Sewers will be designed to provide a minimum velocity of 0.6 m/s at the average daily flow, or average hourly flow rate, and a minimum velocity of 0.75 to 1.05 m/s at the peak diurnal flow rate. When velocities drop below 0.30 m/s during periods of low flow rate, organic solids suspended in the wastewater can be settle out in the sewer.

Sufficient velocity (0.75 to 1.05 m/s) must regularly be developed, minimum once or twice daily, to resuspend and flush out solids which may have been deposited during low flow rate. To keep grit and sand suspended a minimum velocity of 0.75 m/s is required. However, New sewers which are properly designed and constructed should contain only minor quantities of grit or sand. (Unified Facilities Criteria (UFC), 2004)

3.3.6 Erosion and Maximum Velocity

Erosion of sewers is induced by sand and other gritty material in the sewer and also excessive velocity. Thus, the maximum velocity needs to be kept within limits depending upon the martial of the sewer.

Usually, velocities higher than 3.0 m/s should be avoided as erosion and damage may occur to the sewer or manholes.

Table 3.2: Non-eroding Limiting Velocities in Sewers

Sewer Materials	Limiting Velocity in m/sec
Vitrified tiles & glazed bricks	4.5-5.5
Cast iron sewers	3.5-4.5
Stone Ware sewers	3.0-4.0
Cement Concrete Sewers	2.5-3.0
Ordinary brick lined sewers	1.5-2.5
Earthen Channels	0.6-1.2

(Source: Manual on Sewerage and Sewage Treatment, 1993)

3.3.7 Minimum Size

Minimum diameter for a public sewer is kept not below 150mm. However, for hilly areas where extreme slopes are prevalent, minimum size may be 100mm.

3.3.8 Cover

The depth of sewers below ground surface is usually kept to provide a minimum soil cover of 1.0m. This minimum cover is provided from traffic considerations and other consideration of avoiding frequent exposure of laid sewer for example due to the construction of open drains, providing house connection of telephone, electricity, water etc. The maximum depth (usually not more than 6-7 m) depends on the water table, lowest point to be served (ground floor or basement), topography freeze depth and the practical viability.

3.3.9 Slope

Assuming uniform flow, the value of S in the Manning formula is equivalent to the sewer invert slope. Pipe slopes must be enough to provide the required minimum velocities and depths of cover on the pipe. Although it is desirable to install interceptor sewers and large trunk on flat slopes to decrease excavation and construction costs, the resulting low velocities may accumulate objectionable solids in the pipe creating a build-up of hydrogen sulfide, and thus will be avoided. (Unified Facilities Criteria (UFC), 2004)

3.3.10 Hydraulic Formulae

For the designing of sewer system many formulae are used which are described below:

3.3.10.1 Area

Area should be calculated by the following formula:

$$A = \frac{\pi}{4} D^2 \tag{3.2}$$

Where, A = area of flow (m^2)

D = diameter of sewer pipe (m)

3.3.10.2 Hydraulic Mean Depth

Hydraulic mean depth should be calculated by the following formula:

$$R = \frac{A}{P} = \frac{D}{4} \tag{3.3}$$

Where, P is wetted perimeter (m)

$$P = \pi D \tag{3.4}$$

3.3.10.3 Velocity

Sewers are almost exclusively designed for flows with the free water surface. Pressure sewers including siphons are recommended to be avoided as far as practicable. Design equations proposed by Manning, Chezy, Gangrulet, Kutter, Scobey, Hazen Williams etc, have been used for designing sewers and drains. The Manning equation, however, has received most widespread application. The equation is given below:-

$$V = \frac{1}{n} r^{\frac{2}{3}} s^{-\frac{1}{2}} \qquad (3.5)$$

Where,

V = velocity of flow (m/s)

S = Slope of sewer (m/m)

r = hydraulic mean radius (m)

n = Manning coefficient of roughness

The values of Manning coefficient ‘n’ for different materials are given in Table 3.3.

Table 3.3: Manning’s Coefficients for Various Materials

Conduit Material	Manning’s Coefficients
Salt glazed Stone Ware	
Good interior surface	0.012
Fair interior surface	0.015
Cement Concrete Pipes with Collars	
Good interior surface	0.013
Fair interior surface	0.015
Cast Iron	
Unlined	0.013
With spun cement mortar lining	0.011
Spun Concrete Pipes (RCC & PSC) with socket spigot joints(design Value)	0.011
Steel	
Welded	0.013

Rivetted	0.017
Slightly tuberculated	0.020
With spun cement mortar lining	0.011
Asbestos cement	0.011
Plastic (Smooth)	0.011

(Source: Manual on Sewerage and Sewage Treatment, 1993)

For cement concrete pipes of dia. 600mm and above, n value of 0.013 may be used.

3.3.10.4 **Discharge**

In open channels under the force of gravity or in pipes under pressure, the volume of waste water flowing at any given point in the pipe or channel per unit time is called the flow rate or discharge (Q). Discharge should be calculated by the following formula:

$$Q = aV \tag{3.6}$$

Where,

Q = Discharge (m^3/sec)

a = Area of flow (m^2)

V = Velocity of flow (m/s)

3.3.10.5 **Invert Levels**

The bottom level of the pipe wall is called the invert. The upstream invert level and downstream invert level should be calculated by the following formula:

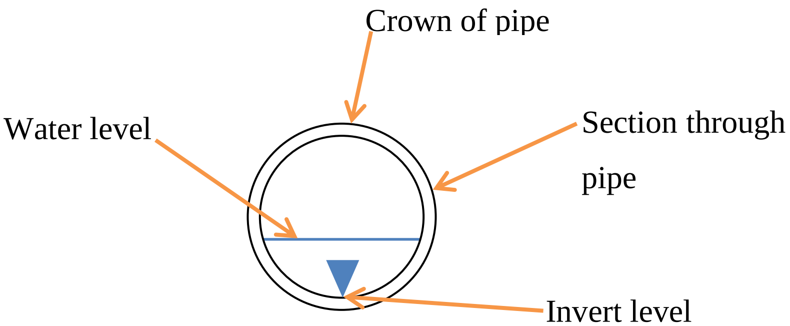


Figure 3.1: Invert Level of Pipe

$$\text{ILUS} = \text{GRLS - Cover - D} - \text{t} \tag{3.7}$$

$$\text{ILDS} = \text{ILUS} - \left\{ \text{Pipelength} \times \left(1/_{\text{slope}} \right) \right\} \tag{3.8}$$

Where, t= pipe thickness.

3.3.10.6 **Fall in Channel Link**

The fall in a pipe may be defined as the vertical drop value by which the pipe drops over a distance. This distance can be between sections of pipe or between manholes. Fall in channel link should be calculated by the following formula:

$$\text{Fall in channel link} = \text{Pipelength} \times \left(1/_{\text{slope}} \right) \tag{3.9}$$

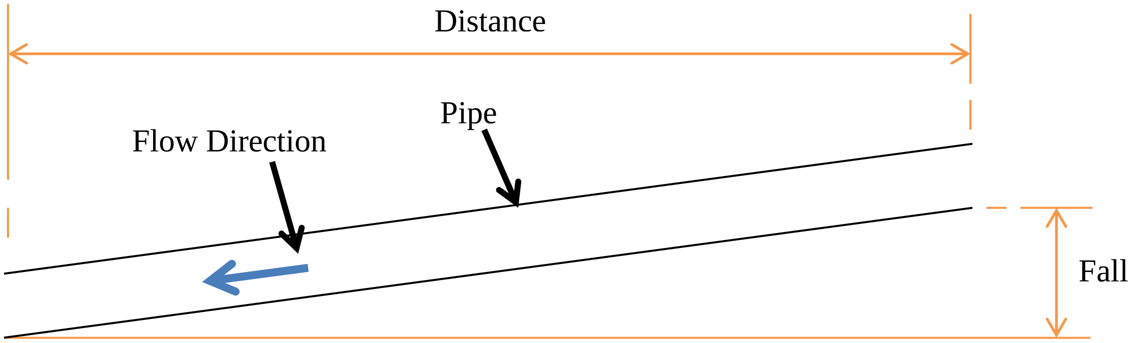


Figure 3.2: Fall in Drainage Pipe

3.3.10.7 **Bed Slope 1 in**

Maintain a uniform slope that provides an allowable minimum and maximum velocity. A flatter slope that is sufficient enough to maintain a velocity of 0.6 m/sec will be permitted only in special cases. Where it is necessary to exceed 3 m/sec, consider using drop structures. (Manual & Letter 2014)

3.3.10.8 **Earthwork**

Earthwork should be calculated by the following formula:

$$\text{ERW} = \text{Length} * \text{Width} \tag{3.10}$$

3.3.10.9 **Depth of Excavation**

Depth of excavation ($\mathrm{DEP\_EX}$) can be calculated by the following formula

$$\mathrm{DEP\_EX} = \left\{ \frac{(\mathrm{DEPTHS} + \mathrm{DEPTHE})}{2} \right\} + \mathrm{CC} \tag{3.11}$$

Where,

$$\mathrm{DEPTHS} = \mathrm{GRLS} - \mathrm{ILUS} \tag{3.12}$$

$$\mathrm{DEPTHE} = \mathrm{GRLE} - \mathrm{ILDS} \tag{3.13}$$

CC= Concrete cover

3.3.10.10 **Partially Full Flow**

Various expressions are also available for flow under partial flow conditions. These terms are described below:

3.3.10.10.1. Constant K

It can be determined by the following formula:

$$CK = QnD^{-\frac{8}{3}}S^{-\frac{1}{2}} \tag{3.14}$$

CK should be less than 0.318.

3.3.10.10.2. Cross Sectional Area

The cross sectional area of flow can be computed for a known value of angle of flow ‘ θ ’ using the relationship:

$$a = \frac{D^2(\theta - \sin\theta)}{4} \tag{3.15}$$

3.3.10.10.3. Depth Ratio

$$DR = \frac{1}{2}\left(1 - \cos\frac{\theta}{2}\right) = \frac{d}{D} \tag{3.16}$$

3.3.10.10.4. Hydraulic Mean Depth

$$HMD = \frac{D}{4}\left(\frac{\theta - \sin\theta}{\theta}\right) \tag{3.17}$$

3.3.10.10.5 Theta

Saatci A. (1990) gave an expression for computing values of 'θ' directly for given values of D, Q and S:

$$\theta = \frac{3\pi}{2}\sqrt{1-\sqrt{1-\sqrt{\pi K}}} \tag{3.18}$$

This is expression based on regression analysis is valid for θ within the range of 0 to 265 degrees.

Benson Jr (1985) also gave an expression, as follows, based on regression analysis for computing velocities directly under part flow conditions:-

$$V = 0.63n^{-0.73}D^{-0.05}S^{0.37}Q^{0.25} \tag{3.19}$$

All the parameters on right hand side of the equations (3.18) & (3.19) are generally known. Thus, velocity can be computed directly although certain small errors may be associated when compared with values calculated using standard analytical formulae.

3.3.10.10.6 Depth of Flow

Depth of flow can be calculated by:

$$\text{Depth} = \text{DR} * \text{D} \tag{3.20}$$

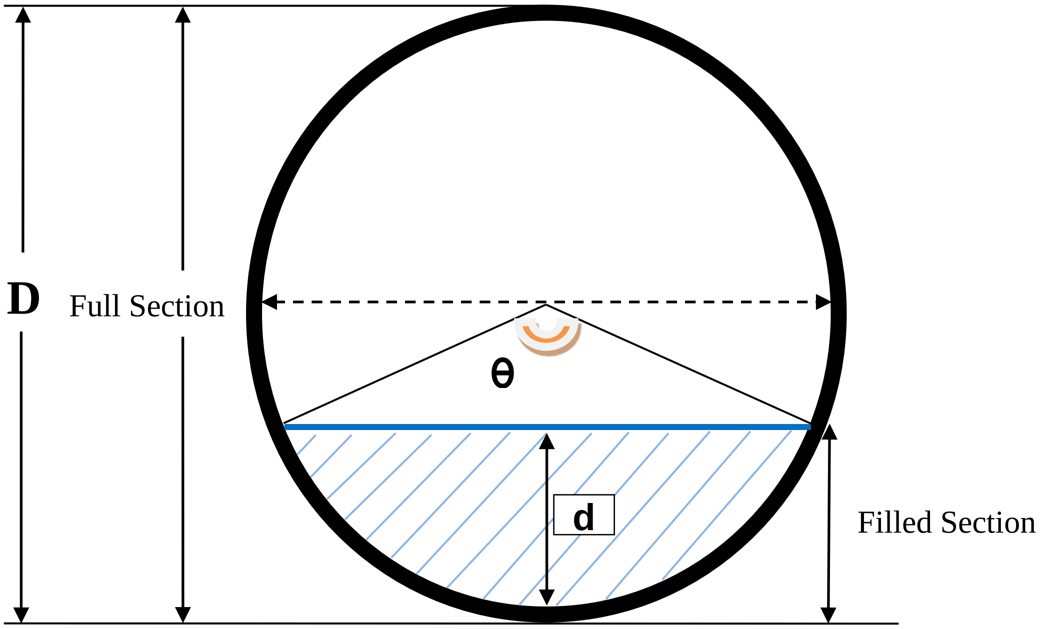


Figure 3.3: The Cross Section of a Partially Flowing Pipe

4. GENETIC ALGORITHM

4.1 Introduction

There are numerous search and optimization techniques for optimization problems in the world. Researchers in the field of engineering, economics, political science, psychology, linguistics, immunology, biology, pharmacy and computer science required an efficient tool to tackle their optimization problems. It is difficult to make realistic model systems because the behavior of the real systems is complex. Generally, an optimization problem to be addressed has several objectives to be optimized. Thus, the problem complexity increases as the number of objectives increases because the objectives are generally contradictory to one another. These type of complex optimization problems have a lot of feasible solutions, but only a few solutions among them are desirable.

In order to use an optimization technique for such complex optimization problems without any complication, the technique should be robust. Goldberg defined robustness as "The balance between efficiency and efficacy required for survival in several different environments." Then we can explain two purposes in constructing an optimization technique as its efficacy and efficiency. Efficacy means whether the optimization technique able to reach the optimum or not. The common purpose of building optimization techniques is this efficacy, that is, their convergence to the optimal of the problem. The other aim efficiency means whether the technique can find a better solution under the constraints the problem has. The technique may not find the optimum solution of the problem due to the constraints but it is essential that better solutions are searched by the algorithm within the constraints in search space. From this point of view, all search techniques are not robust because some optimization techniques tend to find only the local optimal due to its local scope, depends on the existence of derivatives, or requires large computation time. Therefore, Goldberg concluded that "The most important aim of optimization is an improvement. Attainment of the optimum is much less important for complex systems." As for complex systems, Zadeh (1988) also said "Most realistic problems tend to be complex, and many complex problems are either algorithmically unsolvable or, if solvable in principle, are computationally infeasible.” Thus, robust algorithms which can find better solutions under a lot of constraints are required for optimizing complex systems.

The central theme of research on genetic algorithms (GAs) has been robustness. Genetic algorithm, first developed by John Holland in the early 1970’s is becoming an important tool for combinatorial optimization, function optimization and machine learning.

Genetic Algorithms (GAs) begin, like many other optimization algorithms, by defining the optimization parameters and the cost function. They also terminate like any other optimization algorithms, by testing for convergence. (Liang et al. 2004)

Genetic Algorithm is a search algorithm based on the mechanics of natural selection and natural genetics. Genetic Algorithms are part of evolutionary computing. Genetic Algorithms are inspired by Darwin’s theory of natural evolution.

Genetic Algorithms are now finding application in business, scientific and engineering circles. The reasons behind the growing number of applications are clear. These algorithms are computationally simple yet powerful in their search for improvement. (Goldberg, 1989)

4.2 History

The idea of evolutionary computing was firstly introduced in the 1960s by I. Rechenberg in his work “Evolution strategies” (Evolutions strategy in original). Other researchers then developed his idea. Genetic Algorithm have been developed by John Holland, his students and his colleagues at the University of Michigan. Holland’s book “Adaptation in Natural and Artificial Systems” published in 1975 leads this work further. Genetic Algorithm is used by John Koza in 1992 to evolve programs to perform certain tasks. He called his method “Genetic Programming” (GP). (Azim and Swarup, 2005)

4.3 About of GA

Genetic algorithms have been applied in a huge number of ways. This discussion is limited to the optimization of a numerical function. Following the convention of computer programs for the problem will be considered to be a minimization. (If we want to maximize, then minimizing the negative of our function is the same thing.)

In order to apply GAs to an optimization problem, each solution of the problem to be searched by GAs should be encoded as a finite-length string over some finite alphabet. Here a brief description of the difference between the permutation coding and the binary coding is given. Next, genetic operators such as selection, crossover, and mutation strategy are described to construct GAs for optimization problems. These genetic operators should be carefully designed according to the property of the problems. The genetic operators for permutation strings are different from those for binary strings. Before applying GAs to optimization problems, several parameters such as population size, crossover probability, and mutation probability should be specified. After all the genetic operators and the parameters are specified for constructing GAs, we can apply GAs to the optimization problem.

4.3.1 Coding

In GAs, each solution of an optimization problem should be encoded as a finite- length string over some alphabet. The coding techniques can be categorized into the following two methods: (i) binary coding and (ii) permutation coding.

The binary representation is usually used for the coding of solutions. For example, the binary coding is often used for function optimization problems. In such problems, an input parameter vector x on a constraint interval vector [a, b] is encoded by the binary representation. The parameter vector x which optimizes a given function f(x) is searched by GAs in the binary coding space.

The permutation coding is used for sequencing problems such as scheduling problems. For those problems, permutation strings of a set of numbers are more natural representation than binary strings.

Strings which consist of binary or numeral elements are called genotype, and solutions which are decoded from strings are called phenotype. GAs search over the genotype world and strings which are obtained by GAs are decoded into solutions in the phenotype world. That is, the users of GAs can get solutions of their optimization problems after the strings obtained by GAs are decoded into the solutions in the phenotype world.

4.3.2 Evaluation

Each of solutions which are decoded from the strings obtained by GAs is evaluated for optimization problems. GAs searches a string with a better fitness value in the genotype world. In the case of function optimization problems, the function value f(x) is calculated using a solution x decoded from the corresponding binary string obtained by GAs.

When the function value f(x) is better, the string in the genotype world which corresponds to the solution x gets a better fitness value. Then the function value of the solution x is transformed to the fitness value in the genotype world. In the genotype world, it is easy for a string with a high fitness value to survive. For function optimization problems, if the function is to be maximized, the function value itself can be used directly for the fitness value. Otherwise, if the function is to be minimized, the fitness function should be defined as an increasing function by transforming the function in the phenotype world. For permutation problems, the same thing can be said. Scheduling problems have many evaluation functions such as the make span, the total flow time, the tardiness penalty, and so on. Traveling salesman problems also have evaluation functions such as the total travel distance. Because permutations found by GAs are evaluated by the evaluation functions in the permutation problems, the function values can be transformed to the fitness values in the same way of function optimization problems. In this way, a fitness value is assigned to each string in the genotype world.

4.4 Explanation of terms which are used in Genetic algorithm

Different terms are used in the genetic algorithms which are explained below:

Chromosome: A set of genes. Blueprint for an individual.

Gene: A part of the chromosome. A gene contains a part of the solution. It determines the solution. E.g. 13425 is a chromosome and 1, 3, 4, 2 and 5 are its genes.

Individual: Same as a chromosome.

Population: No of individuals present within the same length of the chromosome.

Fitness: The fitness is usually the value of the objective function in the optimization problem being solved.

Fitness Function: This is the function you want to optimize.The Fitness function is a function which assigns fitness value to the individual. It is problem specific.

Selection: A proportion of the individuals existing in a population is selected to breed a new generation.

Crossover: Taking two fit individuals and intermingling their chromosome to create two new individuals.

Mutation: Changing a random gene in an individual.

Generation: An iteration of the genetic algorithm.

4.5 Difference between Genetic algorithm and other algorithm

Genetic algorithms (GAs) are different from normal optimization and search procedures in four ways:

1. GAs works with a coding of the parameter set, not the parameters themselves.
2. GAs search from a population of points, not a single point.
3. GAs uses payoff (objective function) information, not derivatives or other additional knowledge.
4. GAs use probabilistic (stochastic) transition rules, not deterministic rules.
4. GAs can be applied to a variety of problems very easily. (Goldberg, 1989)

4.6 Operators of GA

A simple genetic algorithm that produces good a result in many practical problems is composed of three operators:

1. Reproduction
2. Crossover
3. Mutation

4.6.1 Reproduction

According to Darwin's natural evolution theory, the best ones should survive and create new offspring. Reproduction is a process in which individual strings are copied according to their objective function values, f (fitness function). Here f as some measure of profit, utility, or goodness that we want to maximize. Copying strings according to their fitness values mean that strings with a bigger value have a higher probability of contributing one or more offsprings in the next generation.

There are a lot of methods to select the best chromosomes, for example roulette wheel selection, steady state selection, rank selection and some others. (Goldberg, 1989)

4.6.2 Crossover

This is simply the possibility that two chromosomes will swap their bits. Good value for this is around 0.7. Crossover is executed by selecting a random gene along the length of the chromosomes and swapping all the genes after that point. There are many ways to do a crossover.

4.6.2.1 **Single Point Crossover**

One crossover point is selected in a chromosome, Binary string from beginning of chromosome to the crossover point is being copied from one parent and the rest is copied from the second parent.

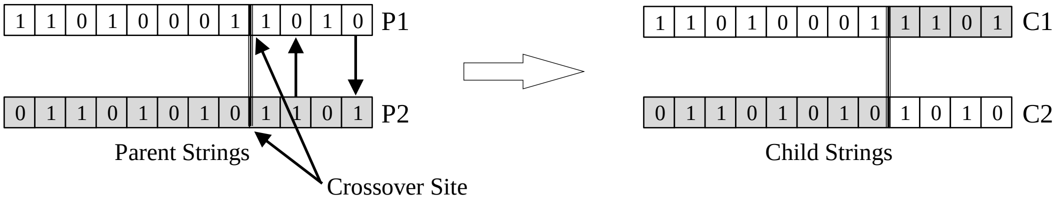


Figure 4.1: Single Point Crossover

4.6.2.2 **Two Point Crossover**

Two crossover point are selected, Everything between the two points is swapped between the parent string, rendering two child string.

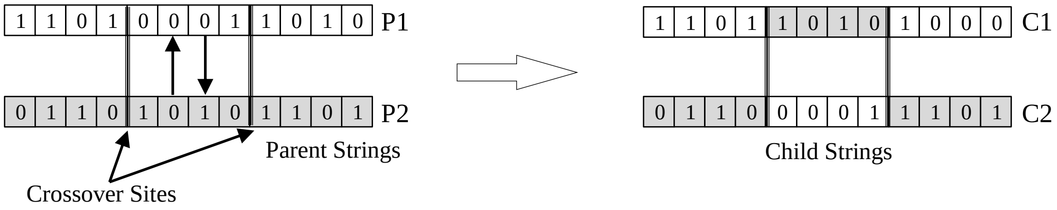


Figure 4.2: Double Point Crossover

4.6.2.3 Uniform Crossover

In this way bits are randomly copied from the first or from the second parent.

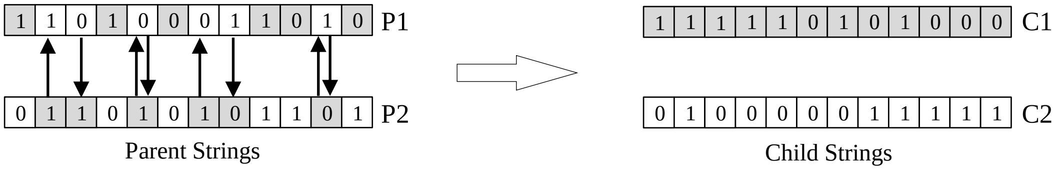


Figure 4.3: Uniform Crossover

4.6.3 Mutation

Mutation is needed because, even though selection and crossover effectively search and recombine extant notions, occasionally they may become overzealous and lose some potentially useful genetic material. The mutation operator provides protection against such an irrecoverable loss. In the simple this is the alteration of the value of a string position. This is the chance that a bit within a chromosome will be flipped (1 becomes 0, 0 becomes 1). This is usually a very small value for binary encoded genes, say 0.002 .

So whenever chromosomes are selected from the population the algorithm first enquires to see if crossover should be applied. Then the algorithm iterates down the length of each chromosome mutating the bits if applicable.

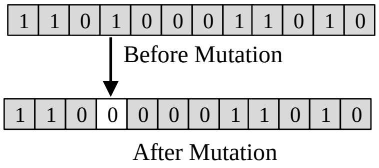


Figure 4.4: Mutation

4.7 Working of Genetic Algorithms

The most common type of genetic algorithm works like this: a population is generated with group of individuals created randomly. The individuals in the population are then evaluated. The fitness function is provided by the programmer and gives the individuals a score based on how well they perform the given task. Two parent individuals are then selected based on their fitness, the higher the fitness, the higher and the chance of being selected. These parent individuals then "reproduce" to create one or more child strings, after which the child strings are mutated randomly. This continues until a desirable solution has been found or until a number of generation reached a certain number, depending on the needs of the programmer. This is represented by a simple cycle of stages-

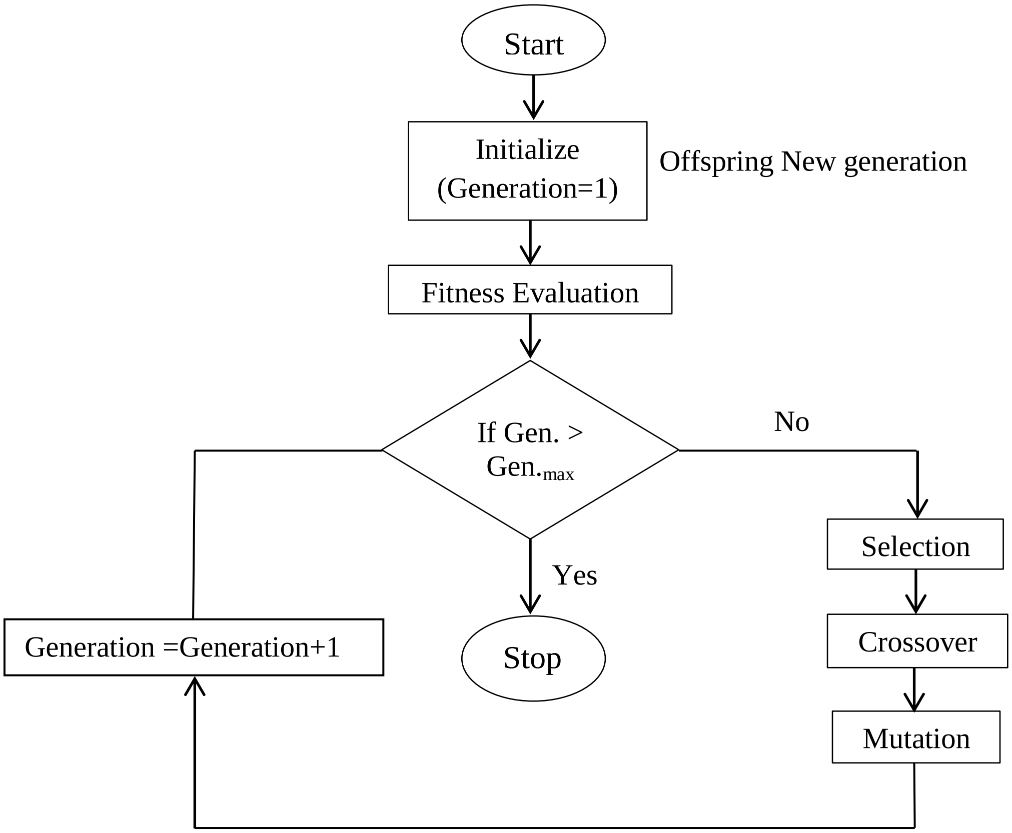


Figure 4.5: The Cycle of a Genetic Algorithm

i) Creation of a "population" of strings,
ii) Evaluation of each string,
iii) Selection of best strings and
iv) Genetic manipulation to generate a new population of strings.

Every cycle in Genetic Algorithms produces a new generation of feasible solutions for a given problem. In the first step, an initial population, describing representatives of the potential solution, is created to begin the search process. The individuals of the population are encoded into bit-strings, called chromosomes. The performance of the strings (often called fitness) is then evaluated with the help of some functions, representing the constraints of the problem. According to the fitness of the chromosomes, they are selected for upcoming genetic manipulation process. It should be noted that the selection process is predominantly responsible for assuring the survival of the best-fit individuals. After the selection of the population, strings is over. The genetic manipulation process consisting of two steps is carried out. In the second step, the crossover operation that recombines the bits (genes) of each two selected strings (chromosomes) is executed. Different types of crossover operators are found in the literature.

The crossover points of any two chromosomes are selected randomly. The third step in the genetic manipulation process is called mutation, where the bits at one or more than one, randomly selected positions of the chromosomes are altered. The mutation process helps to overcome trapping at local maxima. The offspring produced by the genetic manipulation process are the next population to be evaluated.

Example: The Genetic Algorithms cycle is illustrated in this example for maximizing a function $f(x) = x^2$ in the interval $0 = x = 32$. In this example, f (x) is the fitness function. The bigger is the functional value; the better is the fitness of the string. In this example, we begin with 4 initial strings. The fitness value of the strings and the percentage fitness of the total are estimated in Table 4.1.

Table 4.1: Initial Population and Their Fitness Values

Initial population and their fitness values				
String No.	**Initial Population**	**X**	**f(X)**	**Strength Fitness (%of total)**
1.	01101	13	169	14.4
2.	11000	24	576	49.2
3.	01000	08	64	5.5
4.	10011	19	361	30.9
Sum=fitness			1170	100.00

Since the magnitude of fitness of the second string is large, we select two copies of the second string and one each for the 1st and 4th string in the mating pool. The selection of the partners in the mating pool is also done randomly. Here in Table 4.2, we selected partner of 1st string to be the 2nd string and partner of 4th string to be the 2nd string. The crossover points for the first-second and second-fourth strings have been selected after 0th and 2nd bit positions respectively in Table 4.2.

Table 4.2: Mating Pool String and Crossover

Mating Pool String and Crossover				
String No.	**Mating Pool**	**Mates String**	**Swapping**	**New Population**
1.	01101	2	0110[1]	01100
2.	11000	1	1100[0]	11001
3.	11000	4	11[000]	11001
4.	10011	2	10[011]	10000

The second generation of the population without mutation in the first generation is presented in Table 4.3 (Goldberg, 1989)

Table 4.3: Fitness Value in Second Generation

Fitness value in second generation			
Initial Population	**X**	**f(X) (Fitness)**	**Strength(% of total)**
01100	12	144	8.2
11001	25	625	35.6
11011	27	729	41.5
10000	16	256	14.7
Sum-Fitness		1754	100

Here we see that the population average fitness has improved from 293(1170/4) to 439(1754/4) in one generation. The maximum fitness has increased from 576 to 729.

5. MATHEMATICAL MODEL

5.1 Basic Optimization Problem

A simple optimization problem can be expressed in the following way:

Find X, which minimizes f (X)

Subject to the constraints

$g_j(X) \leq 0, j = 1,2,..........m$

Where X = n-dimension vector,

f (X) = objective function involving 'n' numbers of decision variables ($X_1, X_2 .... X_n$),

$g_j(X)$ = constraints and

m = total numbers of constraints.

In the present study, the objective function is the cost of the sewer system which is to be minimized subject to various constraints involving hydraulic, constructional and other considerations.

5.2 Objective Function

The objective function or the cost of sewer system is comprised of cost of many items:

1. Cost of sewers;
2. Cost of earthwork for digging trench;
3. Cost of providing shuttering;
4. Cost of bedding below sewers;
5. Cost of transportation, laying and jointing of sewers;
6. Cost of refilling of trench including disposal of surplus earth and maintenance of metal roads;
7. Cost of providing manholes, etc.

A synthetic approach may, however, associate the various costs into three major costs as describe below:

1. **Cost of sewers** (pipes), which will include the cost of their transportation, joining material, handling etc. The cost of various items included in this head would be dependent on the size of the sewers only.
2. **Cost of earthwork**, which will include the cost of mainly digging, refilling, shuttering etc. This cost would be dependent mainly on the depth of excavation as well as on the size of the sewer.
3. **Cost of manhole**, which will include the cost of providing complete manhole. This cost will also be dependent on the depth of excavation as well as the size of the sewer.

For a given link of the sewer system, the total cost of pipe can be determined by its size and total length. Similarly, the total cost of earthwork may be determined by the average depth of the link, sewer size and its total length. The total cost of the manhole for a link would be dependent on total numbers of manholes on that link. It is customary to design a sewer system from manhole to manhole; therefore, the cost of one manhole may be taken per link whose cost would be dependent on sewer size and depth at upstream of the link. The total cost of the system (value of the objective function) would be the sum of the above three costs for each link.

The total cost of a gravity system for a given layout may therefore be defined as a function of sewer size (D), depth of excavation at upstream (DEPTHS) and depth of excavation at downstream (DEPTHE).

5.2.1 Cost of Pipe

The cost of pipe or cost of sewer (COSTSW) followed the following relationship:

$$\mathrm{COSTSW} = \mathrm{COSTSW}+\mathrm{SD1}$$

Where, SD1 is rate of sewer at the different diameter.

$$\mathrm{SD1}=\mathrm{SD1}+\mathrm{SDD}*\mathrm{UCSW}$$

SDD is the total length of the sewer.

UCSW is the cost of different diameters.

SDD = SDD+LINEL

Table 5.1: Cost of Pipe at Different Diameter

For RCC NP-3 & NP-4 pipes	Cost (₹)
200 mm dia RCC NP_3 pipe	518.00
250 mm dia RCC NP_3 pipe	724.00
300 mm dia RCC NP_3 pipe	973.00
350 mm dia RCC NP_3 pipe	1600.00
400 mm dia RCC NP_3 pipe	1850.00

(Source: RUIDP Schedule of rates, 2013)

5.2.2 Cost of Earthwork

The following relationship was obtained in respect of cost of earthwork (COSTEX)

- If (DEP_EX≤1.5) then

  COSTEX= COSTEX+(ERW*DEP_EX*203)

- IF(DEP_EX≥1.5 and DEP_EX < 3.0) then

  COSTEX=COSTEX + (ERW*1.5*203)+(ERW*(DEP_EX-1.5)*233.5)

Table 5.2: Cost of Excavation at Different Depth

Earth work in excavation in foundation, trenches manholes, road side chambers etc. including dressing of sides and ramming of bottoms, including getting out the excavated material, refilling after laying pipe/ foundation and disposal of surplus excavated material at a lead upto 50m suitable site as per direction of Engineer for following depths, below natural ground / Road top level, trench width payable as per width chart.	Cost (₹)
> upto 1.5 m deep	203.00
>1.5m and upto3.0m deep	233.50
>3.0m and up to 4.5m deep	268.50
>4.5m and up to 6.0m deep	309.00
>6m deep and up to 7.5m deep	355.00
>7.5m deep	408.00

(Source: RUIDP Schedule of rates, 2013)

5.2.3 Cost of Manhole

The following relationship was obtained in respect of cost of earthwork (COSTMH)

COSTMH= SMH (1)*11800+SMH (2)*23100+SMH (3)*40000+SMH (4)*54600

Where, SMH is the sum of numbers of manholes at different depth of excavation.

Table 5.3: Cost of Manhole at Different Depth

Manhole Type	Cost (₹)
Manhole "Type-A" of depth 0.90 m	11,800.00
Manhole "Type-B" of depth 1.70 m	23,100.00
Manhole "Type-C" of depth 2.60 m	40,000.00
Manhole "Type-D" of depth>2.60 m	54,600.00

(Source: RUIDP Schedule of rates, 2013)

5.2.4 Total Cost

The total cost ($TCOST_i$) of ith link can be calculated by:

$TCOST_i = COSTEX_i + COSTMH_i + COSTSW_i$

Therefore, objective function f (X) for total N links can be written as:

$$f(\mathrm{D}, \mathrm{DEPTHS}, \mathrm{DEPTHE}) = \sum_{i=1}^{N} \{(TCOST_i)\}$$

5.3 Constraints

The design of a sewer system has to satisfy many constraints involving mainly hydraulic and other practical consideration.

5.3.1 Part Full Flow Constraint

The depth of the flow in the sewer should not be more than its design value. For a given discharge, diameter and depth of flow there would be a particular value of required slope (Sr). In other words, actual slope of sewer should not be less than this designed required slope. The actual slope of ith link of length $LINEL_i$ is given by:

$$\mathrm{Slope_i} = \frac{\{(\mathrm{GRLS} - \mathrm{DEPTHS}) - (\mathrm{GRLE} - \mathrm{DEPTHE})\}}{\mathrm{LINEL_i}} \le 0$$

The constraints may be required as:

$$Sr_i \ge Slope_i$$

$$Slope_i - Sr_i \le 0$$

$$\text{i.e.} \frac{\{(\mathrm{GRLS} - \mathrm{DEPTHS}) - (\mathrm{GRLE} - \mathrm{DEPTHE})\}}{\mathrm{LINEL_i}} \le 0$$

5.3.2 Minimum Diameter Constraint

The diameter of a link should not be less than the prescribed minimum size (D_{min})

$$D_i \geq D_{min}$$

$$\text{Or } D_{min} - D_i \leq 0$$

In which D_i = diameter of wastewater link i

D_{min} = minimum allowable diameter, taken as 0.2 m in this work.

5.3.3 Diameter Progression Constraint

The diameter of ith link (D_i) should not be less than diameter of previous link (D_{i-1})

$$D_i \geq D_{i-1}$$

$$D_{i-1} - D_i \leq 0$$

In which D_{i-1}= diameter of wastewater link (i-1).

5.3.4 Minimum Velocity Constraint

The velocity of flow in the ith link (V_i) should not be less than defined minimum velocity (V_{min})

$$V_i \geq V_{min}$$

$$V_{min} - V_i \leq 0$$

In which V_i = velocity in link i at peak flow; and

V_{min} =minimum allowable velocity at peak flow, taken as 0.6 m/s in this work.

V_i is a function of discharge (Q), slope and diameter of sewer (D). The slope is a function of upstream and downstream depths as ground elevations are fixed.

5.3.5 Maximum Velocity Constraint

The velocity of flow in the ith link (V_i) should not be greater than defined maximum velocity (V_{max})

$$V_i \leq V_{max}$$

$$V_i - V_{max} \leq 0$$

In which V_i = velocity in link i at peak flow; and

V_{max} = maximum allowable velocity, taken as 3.0 m/s in this work.

5.3.6 Minimum Cover Constraint

There should be some minimum cover (C_{min}) over the buried sewer line to avoid damage to the sewer line.

$$DEPTHE_i - Di \geq C_{min}$$

$$C_{min} - (DEPTHE_i - D_i) \leq 0$$

In which $DEPTHE_i$ = depth of excavation at downstream of ith link

D_i = diameter of wastewater link i

C_{min} = minimum allowable cover, taken as 0.9 m in this work.

5.3.7 Maximum Depth Constraint

The depth of excavation should not exceed practical limits (depmax)

$$DEPTHE_i \leq DEPMAX$$

$$DEPTHE_i - DEPMAX \leq 0$$

In which $DEPTHE_i$ = depth of excavation at downstream of ith link and

DEPMAX = maximum allowable wastewater line depth depending upon subsoil conditions, taken as 5 m in this work.

5.3.8 Invert level progression

The invert level of ith link should also not be above the invert level of its previous link

$$DEPTHE_i - D_i \leq DEPTHS_{i+1} - D_{i+1}$$

$$(DEPTHE_i - D_i) - (DEPTHS_{i+1} - D_{i+1}) \leq 0$$

In which $DEPTHE_i$ = depth of excavation at downstream of ith link and

$DEPTHS_{i+1}$ = depth of excavation at upstream of (i+1)th link

5.3.9 Non-Negativity Constraints

The values of decision variables diameter, depth of excavation at upstream and downstream level may not be negative, that is

$$- D_i \leq 0$$

$$- DEPTHS \leq 0$$

$$- DEPTHE \leq 0$$

Due to constraints of minimum available or allowable commercial diameter and maximum or minimum soil covers which are positive, the above constraints may however, be redundant.

5.4 Penalty Function

A penalty method converts a constrained optimization problem to a series of unconstrained problems, which solutions ideally converge to the solution of the original constrained problem. The unconstrained problems are formed by adding a term to the objective function that consists of a penalty parameter and a measure of violation of the constraints. The measure of violation is nonzero when the constraints are violated and is zero in the region where constraints are not violated.

The penalty functions are of two types:

(i) Interior Penalty Function

(ii) Exterior Penalty Function

In present study there are three conditions in which penalty can be assigned to the objective function:

a) **Penalty due to depth:**

If DEPTH ≥ DEPMAX then
PENDEP=PENDEP+PEN*(AVG-DEPMAX)
And PEN = 0.5×10^6

b) **Penalty due to minimum velocity:**

If PQ ≥ PQMIN and PVEL ≤ PVMIN then
PENVMIN = PENVMIN+PEN*(PVMIN-PVEL)

c) **Penalty due to maximum velocity:**

If PVEL ≥ PVMAX then
PENVMAX=PENVMAX+PEN*(PVEL-PVMAX)

Hence, the total penalty comes out to be sum of all three penalties as:

PC=PENVMIN+PENVMAX+PENDEP

5.5 Overall expression

To sum up, the problem of optimization of a gravity main sewer line with 'N' number of links may be expressed as

Find D_i , $DEPTHS_i$ and $DEPTHE_i$ (i=1 to N)

Which minimizes,

$$f(\mathrm{D}, \mathrm{DEPTHS}, \mathrm{DEPTHE}) = \sum_{i=1}^{N} \{(TCOST_i + PC)\}$$

Subject to constraints,

$$\left.\begin{aligned}
&g(1)_i = Slope_i - Sr_i \leq 0\\
&g(2)_i = D_{min} - D_i \leq 0\\
&g(3)_i = V_{min} - V_i \leq 0\\
&g(4)_i = V_i - V_{max} \leq 0\\
&g(5)_i = C_{min} - (DEPTHE_i - D_i) \leq 0\\
&g(6)_i = DEPTHE_i - DEPMAX \leq 0\\
&g(7)_i = - D_i \leq 0\\
&g(8)_i = - DEPTHS \leq 0\\
&g(9)_i = - DEPTHE \leq 0
\end{aligned}\right] \text{For i=1 to N}$$

$$\left.\begin{aligned}
&g(10)_i = D_{i-1} - D_i \leq 0\\
&g(11)_i = (DEPTHE_i - D_i) - (DEPTHS_{i+1} - D_{i+1}) \leq 0
\end{aligned}\right] \text{For i= 1 to N-1}$$

Hence, for a given N numbers of link the problem involves finding out three N variables subject to 9 N constraints.

6. COMPUTER PROGRAM

6.1 Role of FORTRAN Program

In this study, the proposed method (GA) is coded using FORTRAN to solve the least-cost design and operation of sewerage system problem. The GA tool in FORTRAN is used for the optimal design. By running this GA tool, the optimal solution (best configuration) is obtained.

6.1.1 Introduction

The FORTRAN was developed at IBM by a team of programmers led by John Backus (first published in 1957). The name FORTRAN is an acronym for FORmula TRANslation, because it was bulit to allow easy translation of math formulas into code.

FORTRAN programming language was the one of the first (if not the first) “high level" languages developed for computers. It is referred to as a high-level language to contrast it with machine language or assembly language which communicates directly with the computer's processor with very primitive instructions. Since all that a computer can understand are these primitive machine language instructions, before the execution a FORTRAN program must be translated into machine language by a special program called a FORTRAN compiler. Because of the different processors in different computers, their machine languages are not the same. For a various of reasons, not all FORTRAN compilers are the same. For example, most recent FORTRAN compilers allow operations not allowed by earlier versions. In this research work Force 2.0 Compiler has been used for the execution of the program.

Fortran was initially developed almost entirely for performing numeric computations (Fortran is an acronym for “Formula Translation"). A host of other languages (Pascal, Ada, C, Cobol etc.) has been developed that are more suitable to non-numerical operations such as searching databases for information. FORTRAN has managed to adapt itself to the changing nature of computing and has survived, despite repeated predictions of its death. It is still the dominant language of science and is abundantly used in statistical computing. Fortran 77(established in 1977) is considered the most standard version of FORTRAN. A new standard was developed in 1990 that include some of the useful ideas from other languages, but we will limit ourselves to Fortran 77.

6.1.2 Significant Features of FORTRAN Language

Some of the most significant features of the language are listed below:

1. **Easy to learn** - when FORTRAN was designed one of the objectives was to write a language that was easy to understand and learn.
2. **Machine Independent** - allows for easy transfer of a program from one device to another device.
3. **Ability to control storage allocation** - Programmers were able to monitor the allocation of storage easily (although this is considered to be unsafe practice today, it was quite necessary some time ago due to limited memory).
4. **More natural ways to express mathematical functions** - FORTRAN allows even severely complex mathematical functions to be expressed similarly to regular algebraic notation.
5. **Remains close to and utilizes the available hardware**
6. **Efficient execution** - There is only a roughly 20% decrease in efficiency as compared to machine/assembly code.
7. **More freedom in code layout** – Unlike assembly/machine language, the code does not require to be laid out in rigidly defined columns, (though it still must remain within the parameters of the FORTRAN source code form).
8. **Problem orientated language**

6.1.3 GA Tool in FORTRAN

D.L. Carroll's developed a program which is a FORTRAN version of a genetic algorithm driver.

This code initialize a random sample of individuals with different parameters to be optimized using the genetic algorithm approach, i.e. evolution via survival of the fittest. The selection scheme is used tournament selection with a shuffling technique for choosing random pairs for mating. The routine includes binary coding for the individuals, creep mutation, jump mutation, and the option for single-point or uniform crossover.

Niching (sharing) and an option for the number of children per pair of parents have been added. More recently, an option for the use of a micro-GA has been added.

The seven FORTRAN GA files are in this driver:

1. ga170.f (complete program)
2. ga.inp (input data)
3. ga2.inp (w/ different namelist identifier)
4. ga.out (output of program)
5. ga.restart
6. params.f
7. ReadMe

A sample subroutine "func" is in this which is supply by the user which should be cost function. We should be able to run the code with the sample subroutine "func" the provided ga.inp file and obtain the optimal function value.

The code is presently set for a maximum population size of 200, 4000 chromosomes (binary bits) and 200 parameters. These values can be changed in params.f as appropriate for the problem.

6.2 Basic Feasible Solution

GA was used for solving the problem. The process requires to first generating set(s) of feasible solution(s). The concept of feasible diameter set as given by Swarna et al. (1990) was used for this purpose.

6.2.1 Concept of Feasible Diameter Sets

Swarna et al. (1990) defined feasible diameter set for a link as the range or set of diameters that can satisfy hydraulic constraints such as velocity and partial depth of flow for a specified design flow.

The process of finding feasible diameter set for a link involves finding out feasible slope for that link and comparing the same with minimum and maximum permissible slopes for each of the commercially available diameters. The Manning formula and continuity equation used for this purpose may be expressed as:

$$V = C_1 D^{2/3} S^{1/2} \quad (6.1)$$

$$Q = C_2 D^{8/3} S^{1/2} \quad (6.2)$$

Where,

C_1 and C_2 are constants dependent upon Manning's Coefficient and depth of flow, whose values may be computed for a given depth of flow using relationships described in hydraulic formulae in chapter 3.

The feasible diameter set for a link is found with the following steps:

1. For each of the available commercial sewer size, find minimum slope (S_{min}) from equation 6.1 based on prescribed minimum velocity. Similarly maximum slope (S_{max}) may also be found for prescribed maximum velocity.

2. For specified design flow, find feasible slope (S_f) for each of the commercially available size using equation 6.2.

3. If feasible slope (S_f) of a particular size(s) falls between value of maximum and minimum slopes (S_{max} and S_{min}) of that particular size, than that size would be feasible diameter and corresponding slope a feasible slope.

4. In fact, a size whose S_f is less than S_{min}, may also be a feasible size, provided at S_{min} velocity constraint is not violated. The depth of flow at S_{min} would however, be less than designed depth of flow.

6.3 Present Approach

The present work basically uses the computer program to fit the given problem of sewer system design optimization. Since the method needs the interior feasible initial solution, a program was developed based on the concept of feasible diameter and slope set. The algorithm considers diameter and slope of sewer as a discrete variable. The values taken as input for diameter and slope correspond to the commercially available diameter and slope.

A flow diagram of program is given in Fig.6.1. A flow diagram of EVALOUT SUBROUTINE is given in Fig.6.2. A flow diagram of FUNCTION SUBROUTINE is given in Fig.6.3. The computation of various design factors can be accomplished with the help of hydraulic formula given in Chapter 3. The refinement of optimal design generation also incorporates changing various design factors easily.

6.3.1 Flowchart of GA TOOL in FORTRAN

The basic procedure outlined in Fig. may be explained by the following steps:

1. First input the data into the ga.inp file and the INPUT subroutine.
2. Then program check that the npopsiz and nparam should not be more than indmax and nparamax respectively. If they are greater than an error message is display on the window.
3. Then initialization is done using INITIAL subroutine. In this nchrome (total number of chromosomes required), random number generator etc. initialized.
4. Evaluate the population, assign fitness, and establish best individual using EVALOUT and FUNC subroutine.
5. Now select the best individuals using SELECTN subroutine.
6. Perform crossover between randomly selected pairs.
7. Perform mutation or micro-ga.
8. Now check that best parents was replicated or not using the NEWGEN subroutine.
9. Then take the output in the different output files such as ga.out, sprashant.out, scost.out etc.

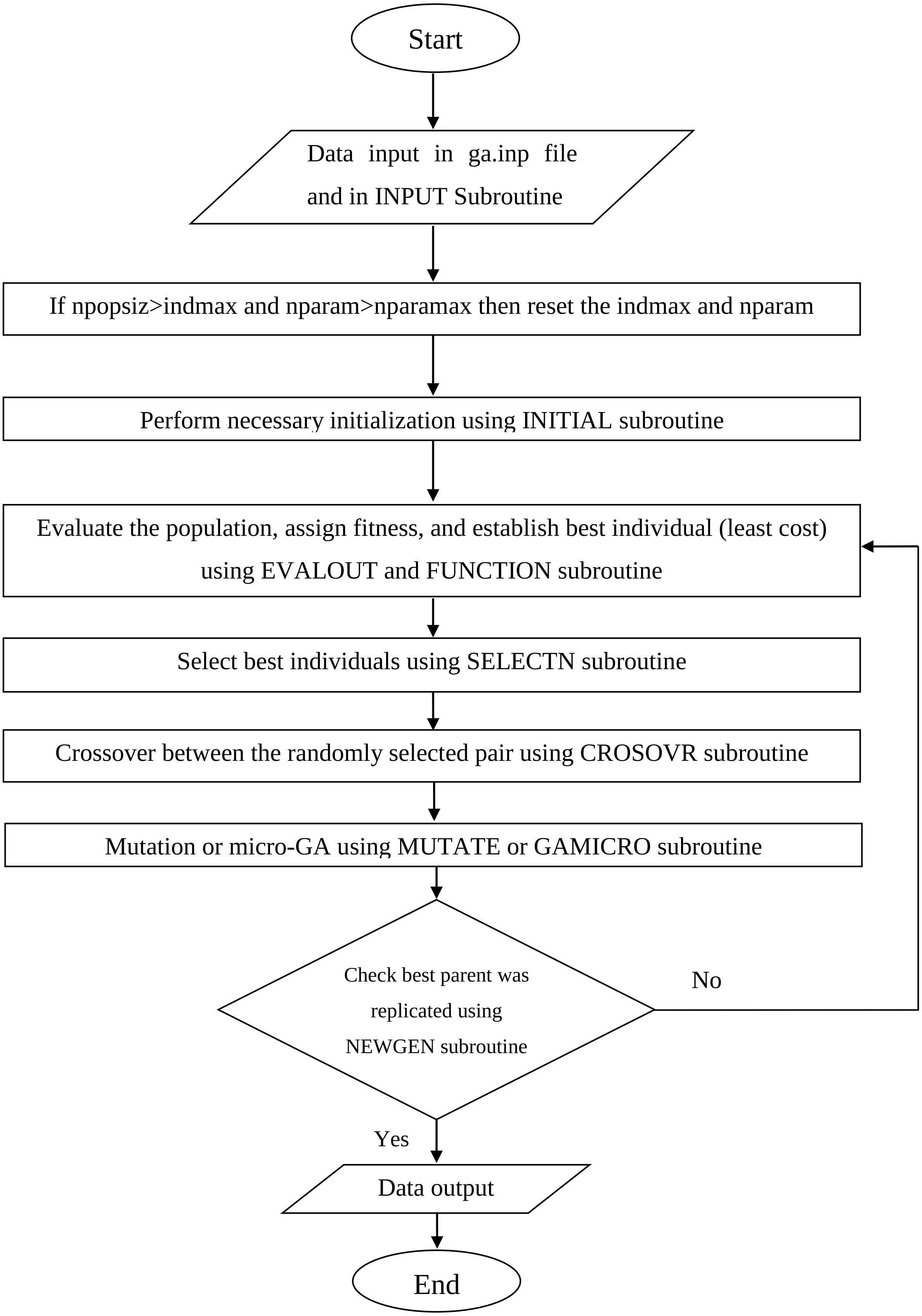


Figure 6.1: Flowchart of the GA tool in FORTRAN

6.3.2 Flowchart of EVALOUT Subroutine

The basic procedure outlined in fig. may be explained by the following steps:

1. Start with first population (J) of first generation (M1).
2. Decode the input data using the DECODE subroutine.
3. Then call the FUNC subroutine to calculate fitness values of the function.
4. Check that the fitness value is best or not.
5. Calculate parameters and average fitness values. Take the output of this subroutine into the ga.out file.

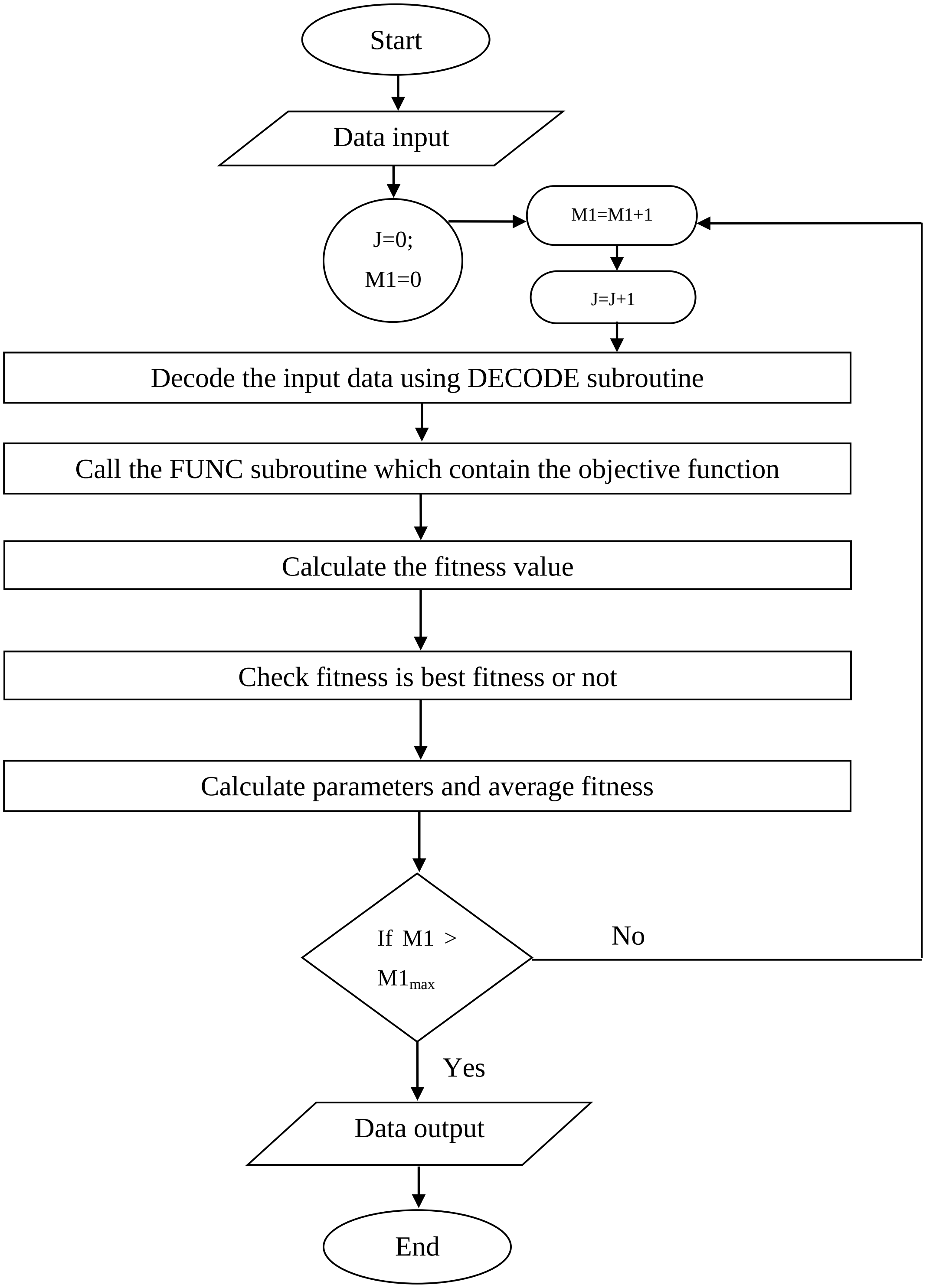
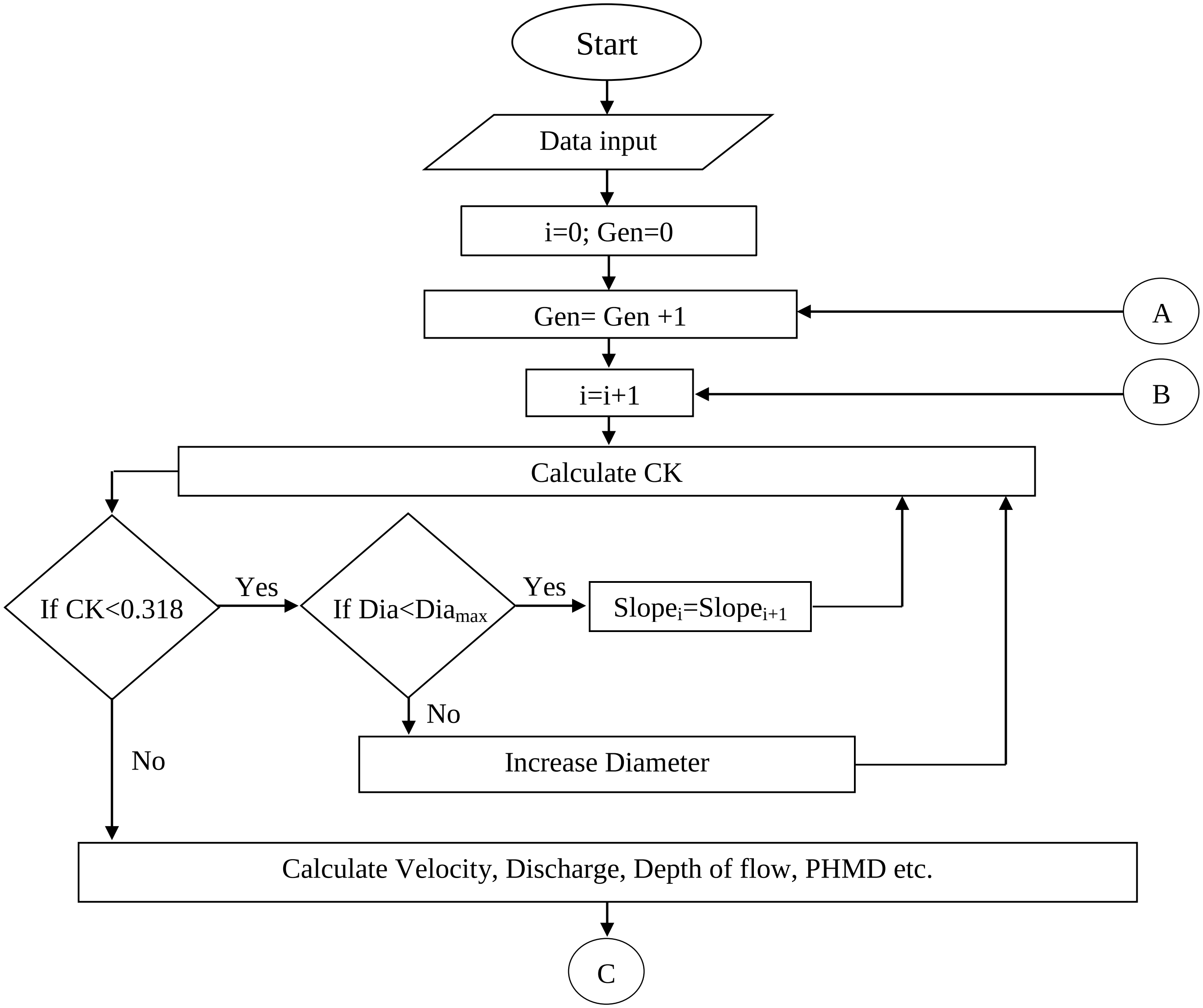


Figure 6.2: Flowchart of the EVALOUT Subroutine

6.3.3 Flowchart of FUNC Subroutine

The basic procedure outlined in fig. may be implemented with the following steps:

1. Start with first link (i=1) of first generation.
2. Calculate constant value ‘CK’, check CK if
    a. CK>0.318 then increase diameter by 0.05m
    b. Further if diameter>0.4m, then increase slope
3. If CK< 0.318, then calculate values of Hydraulic Mean Depth (PHMD), Velocity (PVEL), Depth of flow (DEPTH) and Discharge (PQ) in partial flow condition.
4. Calculate invert levels of upstream and downstream node of a particular link
5. Calculate no of manholes, depth of excavation and earthwork.
6. Calculate cost of sewer (COSTSW), cost of manholes (COSTMH), cost of earthwork (COSTEX)
7. Calculate total cost of sewer system (TCOST)
8. Add the respective penalty cost (PENDEP, PENVMAX and PENVMIN) in TCOST where constraints are violated.
    a. If depth of excavation > DEPMAX, then add PENDEP in TCOST
    b. If velocity > VMAX, then add PENVMAX in TCOST
    c. If velocity < VMIN and discharge (PQ) > minimum discharge (PQ min), then add PENVMIN in TCOST
9. Calculate feasible solution using GA.
10. Take output, check if the solutions obtained is feasible or not


Start
Data input
i=0; Gen=0
Gen= Gen +1
A
i=i+1
B
Calculate CK
If CK<0.318
Yes
If Dia<Dia$_{max}$
Yes
Slope$_i$=Slope$_{i+1}$
No
Increase Diameter
No
Calculate Velocity, Discharge, Depth of flow, PHMD etc.
C

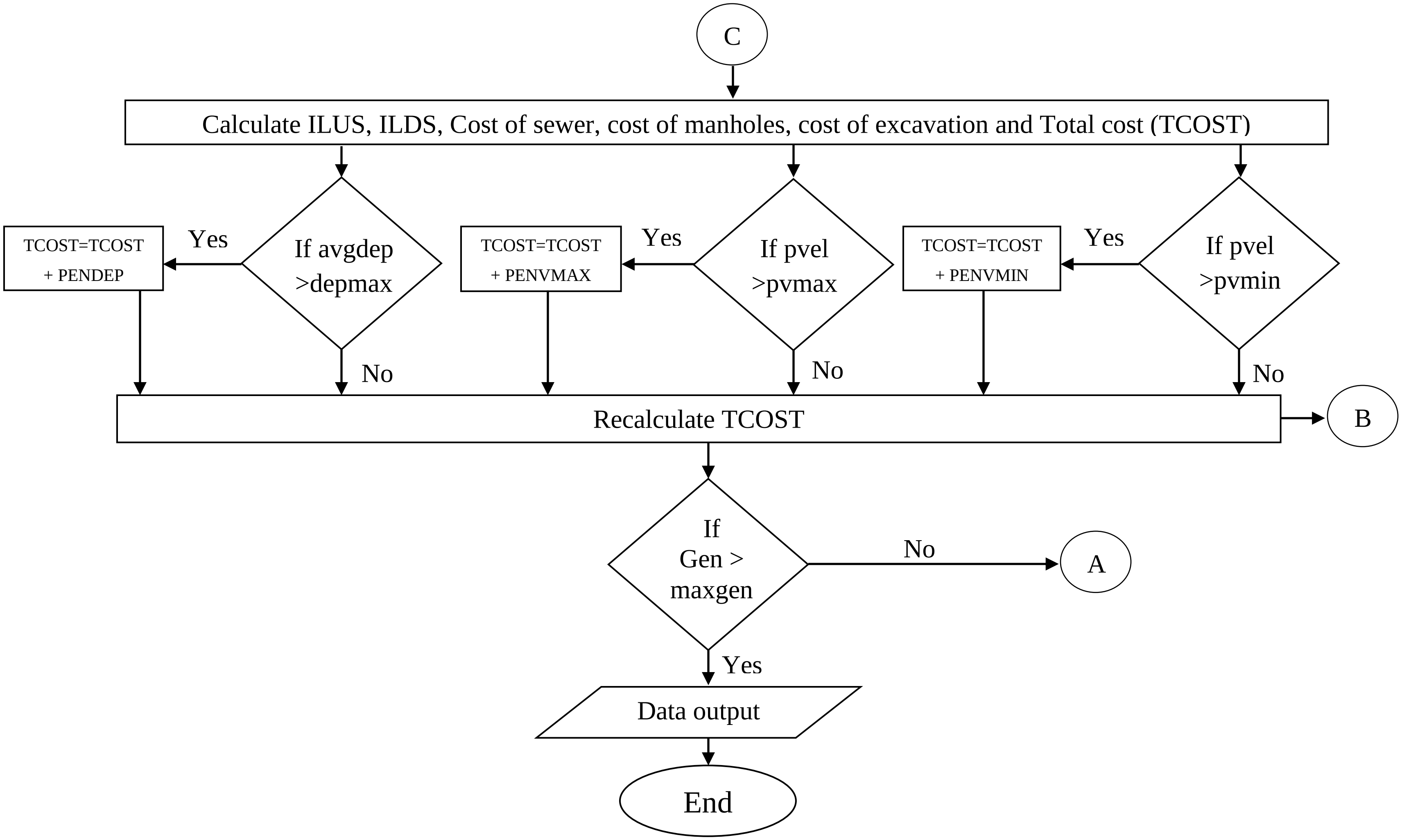


Figure 6.3: Flowchart of the FUNC Subroutine

Since the program involves numerous calculation of function, the gradient of a function, checking of the constraints, etc., comparatively long time is taken to reach to an optimal solution (if more number of iterations are required for optimization).

6.3.4 Input Data of Program

The program requires the following inputs:

1. Link no, u/s node, d/s node, length of each link, discharge in each link, u/s ground level and d/s ground level.
2. Total number of commercially available diameter and slope.
3. Maximum and minimum permissible velocities
4. Manning’s coefficient
5. Total no. of links
6. Minimum prescribed cover and maximum permissible depth
7. Minimum discharge
8. Earthwork factor (EW) taken as 0.25.
9. The Population Size of a GA Run (npopsiz)
10. Number of parameters of each individual (nparam)
11. The jump mutation probability (pmutate)
12. The maximum number of generations to run by the GA (maxgen)
13. The initial random number seed for the GA run (idum)
14. The crossover probability (pcross)
15. Maximum of individuals, i.e. max population size (indmax)
16. Maximum of chromosomes (binary bits) per individual (nchrmax)
17. Maximum of parameters which the chromosomes make up (nparmax)

The above inputs 1 & 2 dependent on a scheme to be designed are fed through a separate file, the data (3 to 8) above which are generally based on prevalent norms are given separately in the program while the remaining data (9 to 17) is provided in the program and separate file.

6.3.5 Output of Program

The output comprising of the following data is generated for each link

1. Link no, u/s node, d/s node, length of each link, discharge in each link, u/s ground level and d/s ground level, diameter, slope, discharge, theta, depth ratio, depth of flow, parea, pvel, phmd, pq, u/s invert level, d/s invert level
2. i, link no, diameter, length, nmhole, depths, depthe, avg of depth , depth range, width, erw, fall, dep_ex
3. Iteration no., i, link no, dep_ex, erw ,COSTEX, COSTMH, COSTSW, PENDEP, PENVMAX, PENVMIN, TCOST
4. binary code, param1, param2, fitness value, average function value, maximum function value, number of crossovers, elitist reproduction on individual, no. of generations, no. of evaluations

The output 1 stored in a file named as “sprashant.out”, output 2 in “spra.out”, 3 in “scost.out”, and 4 in “ga.out”.

7. RESULT AND DISCUSSION

The genetic algorithm developed in this work can be employed to solve several hypothetical as well as real life problems as a part of validation and testing of the program developed.

7.1 Input Data

The input data of sewer network like Link number, upstream node, downstream node, length of each link, discharge in each link, upstream ground level and downstream ground level are given in Table 7.1.

Total number of commercially available diameter and slope are given in Table 7.2.

Maximum and minimum permissible velocities, Manning's coefficient, Total no. of links, Minimum prescribed cover and maximum permissible depth, Minimum discharge, Total no. of generations, Earthwork factor (EW) are given in Table 7.3.

The different parameters for GA are mentioned in Table 7.4.

Table 7.1: Input Data of Sewer Network

S. No.	Link No.	Upstream Node	Downstream Node	Length (m)	Discharge (m^3/s)	Upstream Ground Level (m)	Downstream Ground Level (m)
1.	101	101	102	30	0.12429	346.27	344.79
2.	102	103	104	23	0.14043	345.15	345.09
3.	103	105	104	23	0.14044	345.12	345.09
4.	104	104	102	10	0.00604	345.09	344.79
5.	105	102	106	30	0.00591	344.79	344.68
6.	106	107	108	30	0.00553	345.35	346.4
7.	107	109	108	9	0.00118	346.45	346.4
8.	108	108	110	30	0.00107	346.4	345.75
9.	109	111	112	30	0.00069	347.54	347.12
10.	110	113	112	20	0.00044	348.65	347.12

Table 7.1 continued……

S. No.	Link No.	Upstream Node	Downstream Node	Length (m)	Discharge (m^3/s)	Upstream Ground Level (m)	Downstream Ground Level (m)
11.	111	112	110	30	0.00515	347.12	345.75
12.	112	114	110	20	0.00458	346.22	345.75
13.	113	110	115	30	0.13411	345.75	345.45
14.	114	116	115	30	0.13373	346.87	345.45
15.	115	115	106	30	0.00599	345.45	344.68
16.	116	106	117	30	0.00561	344.68	344.52
17.	117	118	119	30	0.00523	350.65	349.81
18.	118	120	119	12	0.00034	351.08	349.81
19.	119	119	121	30	0.00433	349.81	348.58
20.	120	122	121	18	0.00361	348.67	348.58
21.	121	121	123	30	0.00338	348.58	348.36
22.	122	124	125	30	0.003	351.33	349.02
23.	123	126	125	30	0.00262	348.1	349.02
24.	124	125	123	30	0.00224	349.02	348.36
25.	125	127	123	30	0.00186	349.57	348.36
26.	126	123	128	27	0.0011	348.36	345.23
27.	127	129	128	30	0.00076	345.26	345.23
28.	128	128	130	30	0.00038	345.23	344.87
29.	129	131	130	30	0.00466	346.25	344.87
30.	130	130	117	22	0.00428	344.87	344.52
31.	131	132	117	30	0.00349	344.93	344.52
32.	132	117	133	30	0.00311	344.52	344.35
33.	133	134	135	30	0.00273	353.28	352.07
34.	134	136	135	18	0.00235	352.14	352.07
35.	135	135	137	12	0.00038	352.07	350.78
36.	136	138	137	7	0.00193	351.2	350.78
37.	137	137	139	16	0.00133	350.78	349.79
38.	138	140	141	30	0.00113	350.67	350.02
39.	139	142	141	30	0.00056	350.13	350.02
40.	140	141	146	14	0.00038	350.02	349.4
41.	141	143	139	30	0.12736	351.87	349.79
42.	142	139	146	30	0.12698	349.79	349.44

Table 7.1 continued……

S. No.	Link No.	Upstream Node	Downstream Node	Length (m)	Discharge (m^3/s)	Upstream Ground Level (m)	Downstream Ground Level (m)
43.	143	144	146	11	0.1266	350.41	349.44
44.	144	146	145	30	0.00038	349.44	349.1
45.	145	147	145	20	0.12608	349.27	349.1
46.	146	145	148	20	0.12583	349.1	349.02
47.	147	149	148	26	0.12539	350.64	349.02
48.	148	148	150	24	0.00051	349.02	348.6
49.	149	151	150	26	0.12506	349.02	348.6
50.	150	150	152	30	0.12382	348.6	347.68
51.	151	153	154	72	0.00091	348.82	348.32
52.	152	155	154	30	0.12344	348.35	348.32
53.	153	156	154	30	0.12287	348.41	348.32
54.	154	154	152	24	0.00051	348.32	347.68
55.	155	152	157	20	0.05701	347.68	347.15
56.	156	158	157	25	0.056	347.86	347.15
57.	157	157	159	8	0.05454	347.15	346.02
58.	158	160	161	33	0.05361	351.14	350.64
59.	159	162	161	30	0.00057	352.57	350.64
60.	160	161	163	32	0.00061	350.64	347.58
61.	161	164	163	143	0.0518	347.74	347.58
62.	162	163	159	24	0.00139	347.58	346.02
63.	163	159	165	33	0.00109	346.02	345.04
64.	164	166	167	33	0.00067	346.17	345.98
65.	165	168	167	30	0.06548	346.57	345.98
66.	166	167	169	30	0.0651	345.98	345.65
67.	167	170	169	22	0.06472	345.87	345.65
68.	168	169	165	22	0.06444	345.65	345.04
69.	169	171	165	26	0.06416	345.65	345.04
70.	170	165	172	26	0.0638	345.04	344.39
71.	171	173	172	26	0.06347	345.65	344.39
72.	172	172	174	21	0.00114	344.39	344.26
73.	173	177	176	30	0.00057	346.6	346.56
74.	174	175	176	34	0.06296	347.25	346.56

Table 7.1 continued……

S. No.	Link No.	Upstream Node	Downstream Node	Length (m)	Discharge (m^3/s)	Upstream Ground Level (m)	Downstream Ground Level (m)
75.	175	176	178	76	0.00096	346.56	344.71
76.	176	179	178	38	0.06157	344.79	344.71
77.	177	178	174	38	0.06109	344.71	344.26
78.	178	174	133	13	0.06061	344.26	344.35
79.	179	180	181	31	0.05918	346.7	346.19
80.	180	182	181	31	0.05879	346.23	346.19
81.	181	181	183	10	0.05317	346.19	346.34
82.	182	184	183	30	0.05304	346.54	346.34
83.	183	183	185	30	0.05266	346.34	346.11
84.	184	186	185	30	0.05228	345.9	346.11
85.	185	185	187	30	0.0519	346.11	344.98
86.	186	188	187	30	0.05152	345.65	344.98
87.	187	187	189	30	0.05114	344.98	344.67
88.	188	190	189	30	0.05076	344.86	344.67
89.	189	189	133	30	0.05038	344.67	344.35
90.	190	133	191	33	0.00126	344.35	344.08
91.	191	191	192	33	0.00084	344.08	343.84
92.	192	193	192	30	0.00084	343.92	343.84
93.	193	192	194	36	0.00046	343.84	343.8
94.	194	195	194	26	0.00117	343.98	343.8
95.	195	194	196	27	0.00455	343.8	343.79
96.	196	197	198	30	0.00304	347.23	346.64
97.	197	199	198	30	0.00266	346.7	346.64
98.	198	198	200	30	0.00228	346.64	346.36
99.	199	201	200	30	0.0019	346.46	346.36
100.	200	200	196	30	0.00152	346.36	343.79

Table 7.2: Commercially Available Diameters and Slopes

S. No.	Diameters (mm)
1.	200
2.	250
3.	300
4.	350
5.	400

S. No.	Slopes (1 in n)	S. No.	Slopes (1 in n)
1.	50	13.	650
2.	100	14.	700
3.	150	15.	750
4.	200	16.	800
5.	250	17.	850
6.	300	18.	900
7.	350	19.	950
8.	400	20.	1000
9.	450	21.	1050
10.	500	22.	1100
11.	550	23.	1150
12.	600	24.	1200

Table 7.3: Input Data for Sewer Design

S. No.	Parameters	Values
1.	Maximum permissible velocity	3.0 m/s
2.	Minimum permissible velocity	0.6 m/s
3.	Manning’s coefficient	0.013
4.	Total no. of links	100
5.	Minimum prescribed cover	0.9 m
6.	Maximum permissible depth	5 m
7.	Minimum discharge	0.001
8.	Total no. of generations.	300
9.	Earthwork factor (EW)	0.25 m

Table 7.4: Input Data for GA Tool

S. No.	Parameters	Values
1.	The Population Size of a GA Run (npopsiz)	200
2.	Number of parameters of each individual (nparam)	200
3.	The jump mutation probability (pmutate)	0.02
4.	The maximum number of generations to run by the GA (maxgen)	300
5.	The crossover probability (pcross)	0.5
6.	Maximum of individuals, i.e. max population size (indmax)	200
7.	Maximum of chromosomes (binary bits) per individual (nchrmax)	4000
8.	Maximum of parameters which the chromosomes make up (nparmax)	200
9.	The initial random number seed for the GA run (idum)	-1000,-5762, -16845,-24193, -31728

7.2 Results

It took around 20 minutes of CPU time to reach to optimal solution using GA method on a PC. The result exhibit a final total cost of ₹ 61,00,915 with discrete diameter and slope.

A summary of the results obtained for each idum value are presented in Table 7.5. For idum=-24193 final cost comes out minimum, So solutions for this idum value considered the best solution.
And finally in the Table 7.6 output data of various sewer parameters for idum= -24193 is shown. Also the difference between the slope and diameter of first and last generation demonstrated.

Table 7.5: Cost Summary for Different idum values

S. No.	Different idum Values	Starting Design (No. Of Generation = 1)				Optimal Design (No. Of Generation = 300)			
		Cost of excavation (₹)	Cost of manholes(₹)	Cost of sewer(₹)	Total cost(₹)	Cost of excavation(₹)	Cost of manholes(₹)	Cost of sewer(₹)	Total cost(₹)
1.	-1000	9,29,852	43,15,300	41,32,075	93,77,227	7,24,666	33,22,800	20,59,434	61,06,900
2.	-5762	9,29,441	41,63,200	40,91,355	91,83,996	7,27,434	33,39,700	20,44,195	61,11,329
3.	-16845	9,00,178	41,97,000	38,70,226	89,67,404	7,40,912	33,56,600	20,40,396	61,37,908
4.	-24193	9,21,099	40,97,900	41,40,699	91,59,698	7,26,007	33,39,700	20,35,208	61,00,915
5.	-31728	9,24,735	42,45,400	41,11,880	92,82,015	7,44,143	33,39,700	20,37,116	61,20,959

Best Solution (Least Cost)

Table 7.6: Result of Optimal Sewer Design (idum = -24193)

S. No.	Link No.	Q (m^3/s)	Diameter (m)		Slope (1 in n)		θ	$\frac{d}{D}$	V (m/s)	Ground Level		Invert Level	
			Gen=1	Gen=300	Gen=1	Gen=300				US	DS	US	DS
1.	101	0.12429	350	300	50	50	4.11362	0.73355	2.18923	346.27	344.79	344.17	343.57
2.	102	0.14043	400	350	200	100	4.29188	0.77198	1.72669	345.15	345.09	343.88	343.65
3.	103	0.14044	400	350	200	100	4.29214	0.77203	1.72670	345.12	345.09	343.85	343.62
4.	104	0.00604	400	200	150	200	2.56569	0.35801	0.63102	345.09	344.79	343.62	343.57
5.	105	0.00591	250	200	200	200	2.54887	0.35398	0.62734	344.79	344.68	343.57	343.42
6.	106	0.00553	250	200	200	200	2.49852	0.34199	0.61613	345.35	346.4	344.23	344.08
7.	107	0.00118	350	200	1200	1200	2.07218	0.24521	0.20933	346.45	346.4	345.29	345.28
8.	108	0.00107	350	200	650	950	1.95220	0.21987	0.22085	346.4	345.75	344.08	344.05
9.	109	0.00069	350	200	900	100	1.28659	0.09994	0.41987	347.54	347.12	346.30	346.00
10.	110	0.00044	350	200	850	100	1.14512	0.07974	0.36368	348.65	347.12	346.20	346.00
11.	111	0.00515	400	200	150	50	2.00649	0.23122	0.99131	347.12	345.75	345.23	344.63
12.	112	0.00458	350	200	150	150	2.26676	0.28820	0.64859	346.22	345.75	344.76	344.63
13.	113	0.13411	400	400	250	250	4.62034	0.83691	1.19547	345.75	345.45	344.05	343.93
14.	114	0.13373	400	300	200	50	4.35352	0.78478	2.20651	346.87	345.45	344.83	344.23
15.	115	0.00599	200	200	200	100	2.31012	0.29807	0.80925	345.45	344.68	343.86	343.56
16.	116	0.00561	200	200	150	200	2.50927	0.34454	0.61855	344.68	344.52	343.42	343.27
17.	117	0.00523	400	200	300	50	2.01511	0.23303	0.99582	350.65	349.81	349.29	348.69
18.	118	0.00034	200	200	100	250	1.20593	0.08817	0.24525	351.08	349.81	348.74	348.69
19.	119	0.00433	400	200	150	50	1.91267	0.21174	0.94160	349.81	348.58	348.06	347.46

Table 7.6 continued……

S. No.	**Link No.**	**Q (m^3/s)**	**Diameter (m)**		**Slope (1 in n)**		θ	$\frac{d}{D}$	V **(m/s)**	**Ground Level**		**Invert Level**	
			Gen=1	**Gen=300**	**Gen=1**	**Gen=300**				**US**	**DS**	**US**	**DS**
20.	120	0.00361	200	200	100	150	2.11835	0.25520	0.60576	348.67	348.58	347.55	347.43
21.	121	0.00338	300	200	100	100	1.96549	0.22263	0.68568	348.58	348.36	347.43	347.13
22.	122	0.00300	350	200	100	100	1.90200	0.20957	0.66177	351.33	349.02	348.20	347.90
23.	123	0.00262	200	200	100	100	1.83289	0.19568	0.63541	348.1	349.02	346.98	346.68
24.	124	0.00224	200	200	100	100	1.75663	0.18077	0.60598	349.02	348.36	346.68	346.38
25.	125	0.00186	400	200	50	50	1.52366	0.13821	0.72741	349.57	348.36	347.84	347.24
26.	126	0.00110	250	200	1150	850	1.64859	0.16046	0.22435	348.36	345.23	344.09	344.06
27.	127	0.00076	200	200	350	1150	1.82471	0.19406	0.18645	345.26	345.23	344.14	344.11
28.	128	0.00038	400	200	500	150	1.16182	0.08202	0.30234	345.23	344.87	343.95	343.75
29.	129	0.00466	300	200	150	50	1.95173	0.21977	0.96241	346.25	344.87	344.35	343.75
30.	130	0.00428	400	200	100	100	2.09908	0.25102	0.73493	344.87	344.52	343.62	343.40
31.	131	0.00349	350	200	100	100	1.98298	0.22628	0.69221	344.93	344.52	343.70	343.40
32.	132	0.00311	250	200	100	100	1.92090	0.21342	0.66892	344.52	344.35	343.27	342.97
33.	133	0.00273	250	200	100	50	1.68766	0.16770	0.81895	353.28	352.07	351.55	350.95
34.	134	0.00235	250	200	50	100	1.77955	0.18521	0.61486	352.14	352.07	351.02	350.84
35.	135	0.00038	200	200	450	400	1.31937	0.10491	0.21647	352.07	350.78	349.69	349.66
36.	136	0.00193	350	200	50	50	1.53864	0.14081	0.73582	351.2	350.78	349.80	349.66
37.	137	0.00133	400	200	700	50	1.39490	0.11676	0.65489	350.78	349.79	348.99	348.67
38.	138	0.00113	250	200	700	50	1.33671	0.10758	0.62205	350.67	350.02	349.50	348.90
39.	139	0.00056	400	200	900	200	1.33362	0.10710	0.31015	350.13	350.02	349.01	348.86
40.	140	0.00038	200	200	350	50	1.00886	0.06228	0.43874	350.02	349.4	348.60	348.32

Table 7.6 continued……

S. No.	**Link No.**	**Q (m^3/s)**	**Diameter (m)**		**Slope (1 in n)**		θ	$\frac{d}{D}$	V **(m/s)**	**Ground Level**		**Invert Level**	
			Gen=1	**Gen=300**	**Gen=1**	**Gen=300**				**US**	**DS**	**US**	**DS**
41.	141	0.12736	400	300	250	50	4.18247	0.74863	2.19590	351.87	349.79	349.17	348.57
42.	142	0.12698	400	300	250	50	4.17361	0.74671	2.19512	349.79	349.44	348.57	347.97
43.	143	0.12660	400	300	50	50	4.16486	0.74480	2.19432	350.41	349.44	348.44	348.22
44.	144	0.00038	250	200	400	650	1.40580	0.11852	0.18334	349.44	349.1	347.97	347.92
45.	145	0.12608	400	350	250	100	3.99062	0.70594	1.70328	349.27	349.1	348.00	347.80
46.	146	0.12583	400	350	150	100	3.98614	0.70492	1.70277	349.1	349.02	347.80	347.60
47.	147	0.12539	400	300	250	50	4.13763	0.73884	2.19171	350.64	349.02	348.32	347.80
48.	148	0.00051	400	200	500	250	1.33991	0.10808	0.27900	349.02	348.6	347.58	347.48
49.	149	0.12506	400	300	250	50	4.13035	0.73724	2.19098	349.02	348.6	347.80	347.28
50.	150	0.12382	400	300	250	50	4.10357	0.73133	2.18814	348.6	347.68	347.06	346.46
51.	151	0.00091	400	200	350	150	1.45851	0.12717	0.39881	348.82	348.32	347.68	347.20
52.	152	0.12344	400	400	250	250	4.20160	0.75277	1.19029	348.35	348.32	347.03	346.91
53.	153	0.12287	350	350	100	100	3.93424	0.69301	1.69652	348.41	348.32	347.14	346.84
54.	154	0.00051	400	200	250	100	1.18961	0.08587	0.38130	348.32	347.68	346.80	346.56
55.	155	0.05701	400	250	950	50	3.55643	0.60297	1.84365	347.68	347.15	346.38	345.98
56.	156	0.05600	400	250	900	100	4.21660	0.75600	1.37694	347.86	347.15	346.23	345.98
57.	157	0.05454	400	250	900	50	3.49263	0.58731	1.82721	347.15	346.02	345.01	344.85
58.	158	0.05361	400	250	50	100	4.09225	0.72882	1.36954	351.14	350.64	349.80	349.47
59.	159	0.00057	300	200	450	50	1.11953	0.07631	0.50004	352.57	350.64	350.12	349.52
60.	160	0.00061	300	200	400	50	1.13927	0.07895	0.51105	350.64	347.58	347.10	346.46
61.	161	0.05180	400	300	900	350	4.47820	0.80983	0.83496	347.74	347.58	346.52	346.11

Table 7.6 continued……

S. No.	**Link No.**	**Q (m^3/s)**	**Diameter (m)**		**Slope (1 in n)**		θ	$\frac{d}{D}$	V **(m/s)**	**Ground Level**		**Invert Level**	
			Gen=1	**Gen=300**	**Gen=1**	**Gen=300**				**US**	**DS**	**US**	**DS**
62.	162	0.00139	200	200	50	50	1.41113	0.11938	0.66404	347.58	346.02	345.38	344.90
63.	163	0.00109	250	200	650	50	1.32421	0.10565	0.61500	346.02	345.04	344.58	343.92
64.	164	0.00067	400	200	550	400	1.53121	0.13952	0.25868	346.17	345.98	344.94	344.86
65.	165	0.06548	400	250	50	50	3.78123	0.65720	1.89244	346.57	345.98	345.40	344.80
66.	166	0.06510	400	250	250	50	3.77080	0.65472	1.89049	345.98	345.65	344.80	344.20
67.	167	0.06472	400	250	850	50	3.76043	0.65225	1.88852	345.87	345.65	344.70	344.26
68.	168	0.06444	300	250	200	50	3.75280	0.65044	1.88706	345.65	345.04	344.20	343.76
69.	169	0.06416	400	250	600	50	3.74520	0.64862	1.88558	345.65	345.04	344.39	343.87
70.	170	0.06380	400	250	700	50	3.73546	0.64630	1.88366	345.04	344.39	343.74	343.22
71.	171	0.06347	400	250	900	50	3.72656	0.64417	1.88188	345.65	344.39	343.74	343.22
72.	172	0.00114	300	200	1100	400	1.76505	0.18240	0.30462	344.39	344.26	343.19	343.14
73.	173	0.00057	350	200	100	700	1.57997	0.14807	0.20285	346.6	346.56	345.48	345.44
74.	174	0.06296	300	250	100	50	3.71286	0.64088	1.87910	347.25	346.56	346.07	345.39
75.	175	0.00096	350	200	300	50	1.28114	0.09912	0.59071	346.56	344.71	345.11	343.59
76.	176	0.06157	400	300	800	200	4.08921	0.72814	1.09326	344.79	344.71	343.57	343.38
77.	177	0.06109	400	300	950	150	3.76998	0.65453	1.23229	344.71	344.26	343.29	343.04
78.	178	0.06061	400	250	750	100	4.63733	0.84004	1.38181	344.26	344.35	343.04	342.91
79.	179	0.05918	400	250	650	100	4.43723	0.80172	1.38321	346.7	346.19	345.33	345.02
80.	180	0.05879	400	250	950	100	4.40317	0.79489	1.38280	346.23	346.19	345.06	344.75
81.	181	0.05317	300	250	200	100	4.07121	0.72413	1.36800	346.19	346.34	344.75	344.65
82.	182	0.05304	300	250	150	100	4.06508	0.72275	1.36753	346.54	346.34	345.37	345.07

Table 7.6 continued……

S. No.	**Link No.**	**Q (m^3/s)**	**Diameter (m)**		**Slope (1 in n)**		θ	$\frac{d}{D}$	V **(m/s)**	**Ground Level**		**Invert Level**	
			Gen=1	**Gen=300**	**Gen=1**	**Gen=300**				**US**	**DS**	**US**	**DS**
83.	183	0.05266	400	300	800	250	3.98196	0.70396	0.97158	346.34	346.11	344.65	344.53
84.	184	0.05228	400	300	900	350	4.54595	0.82294	0.83484	345.9	346.11	344.68	344.59
85.	185	0.05190	350	250	450	50	3.42468	0.57054	1.80845	346.11	344.98	344.41	343.81
86.	186	0.05152	400	250	900	50	3.41490	0.56812	1.80564	345.65	344.98	344.41	343.81
87.	187	0.05114	350	250	600	100	3.97918	0.70333	1.36029	344.98	344.67	343.80	343.50
88.	188	0.05076	300	250	150	100	3.96271	0.69956	1.35874	344.86	344.67	343.69	343.39
89.	189	0.05038	400	250	900	100	3.94644	0.69582	1.35715	344.67	344.35	343.39	343.09
90.	190	0.00126	250	200	850	750	1.97676	0.22498	0.25191	344.35	344.08	342.91	342.87
91.	191	0.00084	400	200	50	150	1.42814	0.12215	0.38892	344.08	343.84	342.87	342.65
92.	192	0.00084	300	200	1150	250	1.52761	0.13890	0.32630	343.92	343.84	342.80	342.68
93.	193	0.00046	350	200	450	1200	1.60330	0.15224	0.15759	343.84	343.8	342.65	342.62
94.	194	0.00117	350	200	900	150	1.55867	0.14431	0.43131	343.98	343.8	342.85	342.68
95.	195	0.00455	250	200	150	150	2.26249	0.28723	0.64738	343.8	343.79	342.62	342.44
96.	196	0.00304	200	200	100	50	1.73720	0.17705	0.84631	347.23	346.64	346.11	345.51
97.	197	0.00266	350	200	50	100	1.84047	0.19718	0.63832	346.7	346.64	345.58	345.28
98.	198	0.00228	250	200	50	100	1.76505	0.18240	0.60925	346.64	346.36	345.28	344.98
99.	199	0.00190	300	200	50	50	1.53227	0.13970	0.73225	346.46	346.36	345.34	344.74
100.	200	0.00152	350	200	50	50	1.44466	0.12487	0.68295	346.36	343.79	343.27	342.67

8. CONCLUSION

The present work fulfills more than the objective of developing an efficient algorithm for the optimal design of a gravity sewer system.

In this dissertation work, the Genetic Algorithm was applied to the problem to finding optimal pipe diameters and slopes for the conjunctive least-cost design and operation of a sewerage system network. , the problem representation is simple, and due to global sampling capability, the probability of obtaining a global optimum solution is more. Total possible pipe and slope permutations were 120^{100} (approx. 8.282×10^{107}) and it is very difficult to find out the optimal pipe diameter and slopes from such a large combinations if not using optimization technique (GA). Hence, GA is very promising technique as it can save a lot of time.

An initial number of 200 populations were used for the each generation. The total numbers of generations were 300. Five different initial random number seed for the GA run (idum) were used. The total cost of the best solution obtained from the idum= -24193 was considered to be the Optimal Cost of the sewerage system and the pipe diameters and slopes obtained for this idum value were considered as the Optimal Pipe Diameters and slopes. It can be seen that a reasonable difference in cost has been obtained after applying optimization technique over sewerage system and that is around ₹ 30,58,783.

It is hoped that program shall find direct application in field problems of design of gravity sewer system. As the program developed for sewer system analysis uses the commercially available diameter and slopes. And it can handle discrete parameters of sewer system also.

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